CONSEIL PERMANENT INTERNATIONAL
POUR L'EXPLORATION DE LA MER
CHARLOTTENLUND SLOT — DANEMARK

JOURNAL DU CONSEIL

VOL. XXII · NO. 1

PUBLIÉ PAR LE BUREAU DU CONSEIL

Contents list and
of each volu

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PERIODICAL
Journal Du Conseil
2354[60] V.22-23
1956-58

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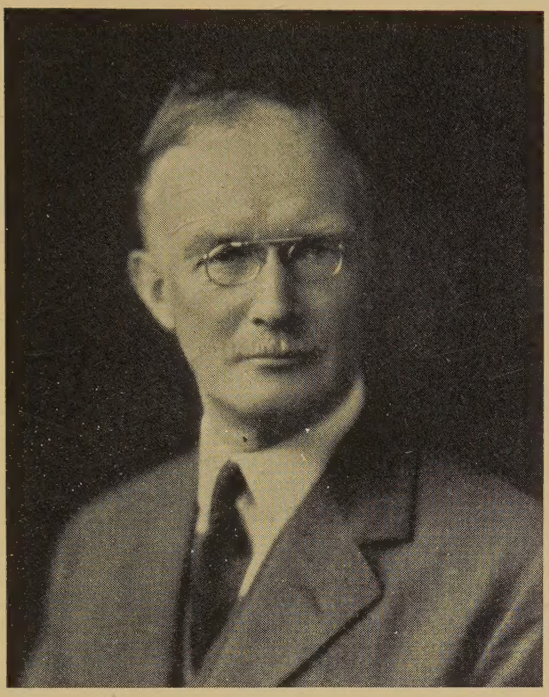

Donald John Matthews

1873—1956

THE death of D. J. MATTHEWS has removed from the ranks of oceanographers one who had already reached man's estate when the International Council for the Exploration of the Sea was founded, and there can be but few of his time and experience remaining. Because he devoted so much of his long life to oceanography, there are many who now lament the loss of a kindly, wise, and helpful colleague.

MATTHEWS was born at Surbiton on 3. July 1873, and died in the same county at Camberley on 6. January 1956. His long life of nearly 83 years was filled with an astonishing variety of activities

upon which information kindly supplied by Mr. F. S. RUSSELL has thrown most light.

He received his general education at Hartley House, Winchfield, from 1886 to 1888, and thereafter at Marlborough for four years. There he met that great figure of International Council fame Henry MAURICE, and the two remained close friends up to the time of MAURICE's death in 1950. After leaving Marlborough, where he had become a school prefect, MATTHEWS went for a short time to work in an electrical accumulator works near Zürich. He was back in England to enter University College, London, in October 1892 where he took courses in chemistry, physics, mathematics, zoology, and botany. He made chemistry his chief subject, gained a Cloth Worker's Scholarship, and became a silver medallist in general chemistry. Whilst at University College MATTHEWS assisted Sir William RAMSAY in his early work on argon and helium. RAMSAY described him as somewhat delicate and reported that MATTHEWS never proceeded to his Degree in Science after passing the Intermediate B.Sc. examination. A letter written by RAMSAY in 1902 contains the following references to MATTHEWS:— "he helped me in my gas-work and indeed worked up the minerals which proved subsequently to contain helium; indeed he did all the preliminary work of devising methods of extraction under my direction. He was a most capable manipulator. During all this time he worked during his off hours with the microscope chiefly at microscopic marine animals".

In 1895 MATTHEWS left University College and went for a few months to the laboratory of Mr. W. MACNAB, F.I.C., in Westminster where he did general analytical work, but in November 1895 he had moved to Larne near Belfast. There he worked for the British Aluminium Company as chemist, and towards the end of his time there he was engaged chiefly on research. It is understood that he did some work on the metallurgy of ships' propellers then. In February 1899 he transferred to the rolling mills and foundry of the same company located at Milton in Staffordshire, and was made Under-Manager six months later though he still retained charge of the chemical department. MATTHEWS left that employ in May 1900 because he found it impossible to stand the heat of the casting shop where he had to spend most of his time. His move was back to the laboratory of Mr. MACNAB where, for two years, he carried out electro-chemical research for Mr. HARBORD who was head of the analytical department at the Royal Indian Engineering College at Coopers Hill. During that time he is understood to have done some special joint work on cerium alloys. Accepting from Mr. HARBORD the offer of a post in his (Mr.

HARBORD's) own laboratory, MATTHEWS moved again in May 1902, but his stay was brief.

It was in November of the same year (when he was 29 years of age) that MATTHEWS took the step which was to bring him into the field of oceanography. He wrote to Dr. E. J. ALLEN applying for the post of chemist at the Plymouth laboratory of the Marine Biological Association of the United Kingdom (M.B.A.); he did this at the suggestion of Sir William RAMSAY who was well aware of his interest in things of the sea. In his application MATTHEWS rightly described himself as fairly expert in microscopic work as a result of having devoted a considerable part of his leisure to marine zoology. He recalled that he had, some years earlier, often made trips in the M.B.A.'s vessel when holidaying in Plymouth with Mr. Frank BEDFORD, and added that whilst at Larne, he had been part owner of a three-ton yacht and so was used to sailing. Having been appointed "Hydrographer" at the Plymouth laboratory in November 1902, MATTHEWS was already working there the next month and during the years which followed, he published a series of very important papers on the oceanography of what is nowadays called the Celtic Sea.

In 1913 he was away in the "Scotia", accompanied by the meteorologist Mr. (now Sir) G. I. TAYLOR and the biologist Mr. L. R. CRAWSHAY, working on the oceanography and the ice conditions off the coasts of Newfoundland and Labrador. Arising out of the "Titanic" disaster the investigations were undertaken at the instance of the then Board of Trade to discover "whether any steps could usefully be taken to render the steamship routes across the Atlantic more safe by the establishment of ice patrol or ice observation vessels to the north of these routes". Fifteen weeks were spent at sea in the ice area during the course of the investigations, and the report subsequently produced by MATTHEWS and published in 1914 by His Majesty's Stationery Office was a model in respect both of content and presentation. He returned from the expedition to resume work at Plymouth at the end of August 1913 but resigned from his post there in January 1917.

After the international investigations carried out to serve as British implementation of the plans laid by the International Council for the Exploration of the Sea were transferred from the M.B.A. to the then Board of Agriculture and Fisheries in 1910, MATTHEWS devoted half his time to working for the M.B.A. and half to working for the Irish Fishery Department. This he did until January 1916, at which time he undertook work for the Devonport Military Hospital, investigating the chemical aspects of cerebro-spinal meningitis but working in the Plymouth laboratory.

At some time MATTHEWS travelled in the Far-East on scientific business, visiting Colombo, Singapore, Hongkong, Shanghai, and Japan, but, so far as is known to the writer, his next post after leaving Plymouth was at Rothamsted Experimental Station though he never really settled down to agricultural science. He was there in 1920, in which year he published a paper on the determination of ammonia in soils. A report relating to his work at Rothamsted describes him as always a meticulous worker and a loyal colleague, but adds that his heart was really in oceanography to which he always wanted to get back. He is spoken of as being at that time of a rather retiring disposition but as having qualities which earned for him "much quiet popularity" added to by great respect for his skill in photography. The next known of MATTHEWS is of his having taken service with the Admiralty Scientific Research Establishment in the rank of Principal Scientific Assistant. Precise details of joining date are not known to the writer, but MATTHEWS was writing from the Hydrographic Department of the Admiralty in 1920, and it was there that he made by far his longest stay occupied with oceanographical matters, remaining seconded to the Hydrographer of the Navy until October 1936.

Most people who knew him really well will remember him best as working in the last-named post. MATTHEWS was often to be met with after his retirement at the age of 63 for he was a fairly regular attender at the meetings of the Challenger Society, but he seems to have been fully occupied in those days with his hobbies at home; we hear of him again pursuing oceanographical investigations in 1944. In that year, and (it is thought) in the earlier years of World War II, he busied himself with outdoor marine researches undertaken in Admiralty interest. After the death of his wife in 1951 MATTHEWS suffered failing health and was taken for a time to live with his soldier son in Germany. The next known of him is of his return to England (when his son was ordered to the Far-East) and of his living in the Camberley nursing home, where he died.

All opinions of MATTHEWS bear testimony to his kindly, wise, and helpful disposition, to the meticulous nature of his work, and to his great skill in his useful and exacting hobbies of microscopy, photography, and wireless. He was a great wireless enthusiast and built his own receivers from the early days of radio up to 1940, and he left behind him a wealth of home-made photographic equipment.

MATTHEWS played an important part in the affairs of the International Council for the Exploration of the Sea, and attended its reunions in the capacity of expert in 1909 and 1924, and from 1928 to 1938. The opinion has been expressed that the greatest

debt owed to him is in respect of his efforts to make the determination of salinity by titration very accurate. He will also be remembered very well in Council circles for two important works published by it—his density tables of 1932 and his specific volume tables of 1935, and memories of his expert contributions to, and his wise counsel at, meetings of the Hydrographical Committee will long remain with those who knew him well in those days. MATTHEWS played no less a part in the affairs of the International Association of Physical Oceanography (I.A.P.O.) attending its meetings as early as that held in 1927 in Prague. He was for a time a member of its Executive Committee, and he served also on some of its specialist subcommittees besides being for a period Secretary of the Oceanographical Subcommittee of the British National Committee for Geodesy and Geophysics, through which the contacts with I.A.P.O. are operated.

MATTHEWS was elected a Fellow of the (now Royal) Institute of Chemistry in 1919.

British colleagues will remember him particularly well from his attendance at numerous meetings of the Challenger Society; indeed the last remembrances of many will be of his coming to those occasions for some years after the end of World War II up to the time when he had become noticeably frail. MATTHEWS joined the Society as early as 1906 and its minutes back through the years contain many records of contributions and demonstrations made by him. In 1905 he was exhibiting charts illustrative of the physical conditions in the English Channel during 1904 and 1905. In April 1908 he was lecturing on "Practical Methods for the Collection and Investigation of Water Samples and Temperature Observations". In 1911 he was elected to the Advisory Committee, and in 1912 he read a paper on a new bottle (of his own devising) for the collection of water samples for bacteriological examination. In 1916 he lectured on the hydrographical observations made during the "Scotia" expedition already referred to, and in 1923 he discoursed on the temperature of the bottom water of the oceans. Later in the same year he gave a demonstration of a current-meter before the Society, which held such a high place in his regard that he attended its meetings regularly until October 1950.

It would be a lengthy business to detail the papers which MATTHEWS published during the long time that he was engaged with oceanographical matters, and we shall not do it here. Perhaps his chief monument will be his justly renowned "Tables of the Velocity of Sound in Pure and Sea Water for use in Echo Sounding and Sound-Ranging". These tables, issued as Publication H.D. 282 by the Hydrographic Department of the British Admiralty, have

long been an invaluable tool in many hands, and were adopted provisionally in 1947 at the conference of the International Hydrographic Bureau "for the purpose of obtaining uniformity in the correction, prior to charting, of sonic soundings in offshore areas where the use of the bar check is not feasible".

Whilst at school MATTHEWS transferred from the Classics to the Science side, and in his declining years visitors would find him deriving great solace from a beloved Greek text.

His passing is a sore loss to the science which he loved and did so much for, and sympathy is extended to his son Major Alan MATTHEWS who is at present serving in Singapore, to the wife of the latter who remains in England with the two children, and to the three sisters of D. J. MATTHEWS who survive him.

J. N. Carruthers

A Conductivity Bridge for Measurement of the Salinity of Sea Water[1)]

By

Karl E. Schleicher and **Alvin Bradshaw**

Introduction

Among the various methods known for determining salinity of sea water in the laboratory, the KNUDSEN method, based on silver nitrate titration of halides in unknown and standard (Copenhagen) water, has the longest history and has been used the most extensively. Its advantages when compared with many of the other proposed methods have been its combination of relatively high accuracy with speed and simplicity. Around 1922, however, an instrument was built for the U.S. Coast Guard by WENNER *et al.* (WENNER, SMITH, and SOULE, 1930) for determining salinity, which used the conductivity properties of sea water. In this instrument some of the difficulties due to polarization phenomena in conductivity cells and due to bath temperature fluctuations were reduced in importance (1) by introducing a conductivity cell containing sea water in an adjacent arm of the measuring bridge, (2) by making the principle of the determination one in which the conductivity of the sample sea water is compared to that of a standard at the same temperature, and (3) by using a 1000 c.p.s. power source with low distortion. In its present form, this instrument has a precision of better than $\pm$ 0·005 $^0/_{00}$ (BARNES, 1952) in salinity as compared with about $\pm$ 0·02 $^0/_{00}$ (CARRITT, 1952, and ISELIN, 1936) for the KNUDSEN method.

In addition to the advantage of accuracy the Coast Guard instrument is well suited for shipboard use. The difficulties of working with fragile glassware and maintaining the laboratory at constant temperature are not present. Its suitability for use at sea is of great importance, for aside from the obvious advantages of having the salinity data complete at the conclusion of a cruise, the knowledge of salinity obtained shortly after a hydrographic station has been made can be of help in planning future stations and also makes possible the spotting of a faulty Nansen bottle.

[1)] Contribution No. 810 from the Woods Hole Oceanographic Institution. This work was carried out under Contract NObsr-43270 with the Bureau of Ships.

For these reasons and others it was considered desirable to build an instrument similar to the Coast Guard instrument for use on the Woods Hole Oceanographic Institution research vessels but to incorporate several improvements which were thought to be needed. Among the suggested improvements were smaller conductivity cells, at least semi-automatic balancing of the bridge and recording of the instrument reading on a chart, and a re-design of the constant-temperature bath. The design of the instrument has also been influenced by the experience of working with the STD (JACOBSON, 1948).

Description of Instrument

The functional arrangement of the various component parts is shown in a block diagram (Fig. 1). The conductivity bridge is an AC impedance bridge, powered by a stabilized 1000-cycle oscillator. Arm A of the bridge is connected to any one of five conductivity cells (X or sample cells) which contain unknown samples. Arm B is connected to a sixth conductivity cell (Y cell) which contains sea water around $35\,^0/_{00}$ salinity. Arm C (the components of which are precision resistance decades) is the "standardizing" arm, variable from about 60 ohms to 1171 ohms in steps of 0·01 ohms. Before each reading this arm is set at a value which is determined when the bridge is standardized. Arm D is the "reading" arm made up of precision resistance decades and a potentiometer (appropriately shunted to minimize contact resistance effects) which is operated by a servo-motor. The decade section, variable in 1 ohm steps is set manually to a value within 1 ohm of the final resistance value of the arm for bridge balance. The servo-operated, 2 ohm range, potentiometer section completes the balance and its change in resistance is recorded on a time-driven chart. The total range of arm D is from about 260 ohms to 1370 ohms.

Neither the WAGNER ground circuit to eliminate the effect of ground admittances[1]), nor the variable capacitors used to balance out the capacity effects of the cells are shown in Figure 1. That part of the bridge exclusive of the conductivity cells is contained in a steel cabinet set up above the rest of the instrument. The components are mounted so as to minimize hand capacity effects and the cabinet is heated to prevent condensation.

The output of the bridge is amplified and fed to a phase detector where the 1000-cycle signal is converted to direct current. For this purpose the necessary reference signal is taken directly from the output of the oscillator. This reference signal, after being amplified, is used as a gating voltage in a diode phase detector circuit. The output of the phase detector is a DC voltage whose polarity depends upon the direction of unbalance of the bridge and whose magnitude is zero when the bridge is balanced. This DC voltage is fed to a chopper-type servo-amplifier which controls the servo-motor mentioned above. An auxiliary monitoring circuit amplifies the unbalanced bridge output and operates a "magic eye" tuning indicator and earphones to permit checking of the servo-system.

[1]) See HARRIS, F. K., (1952) Electrical Measurements, John Wiley & Sons, Inc., New York, p. 733, for a discussion of the WAGNER ground and references.

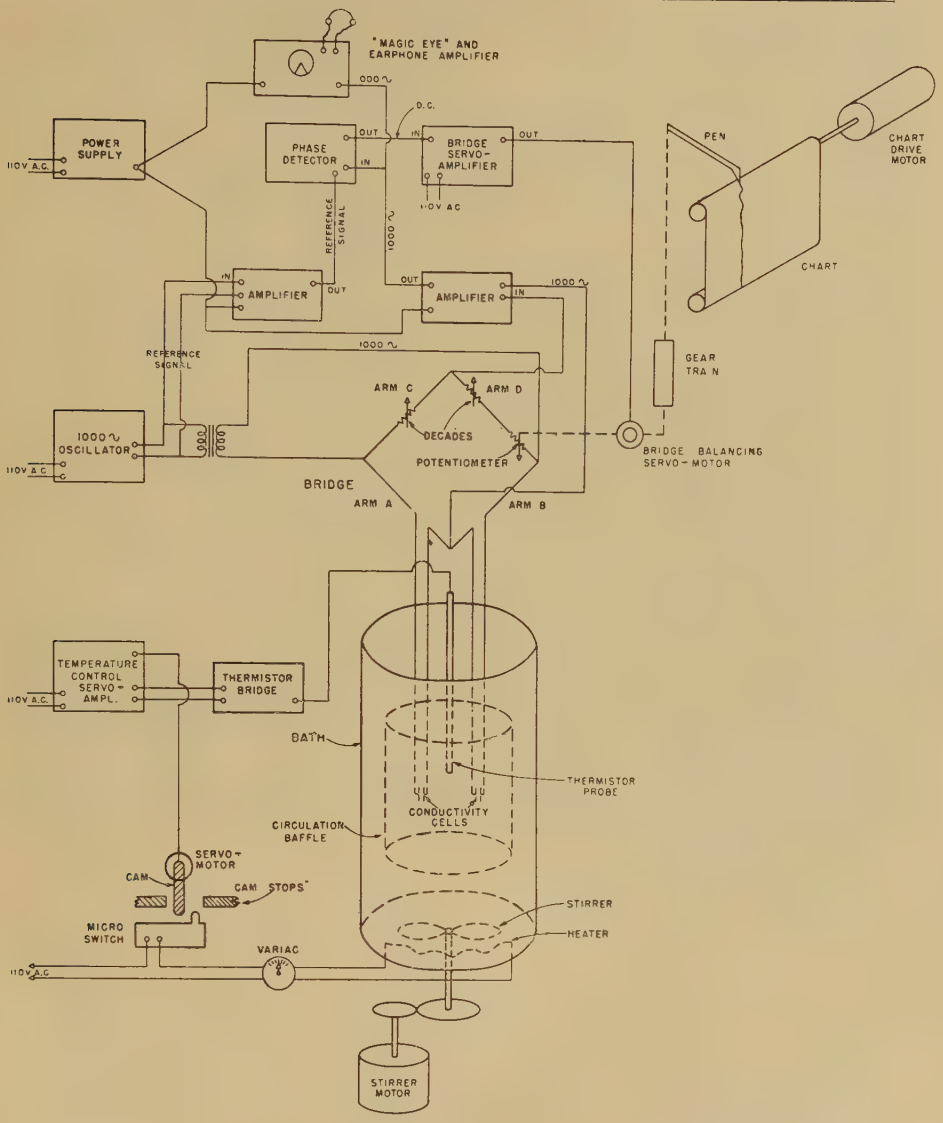

Figure 1. Schematic diagram, showing the general arrangement.

Since the capacity effects of the conductivity cells are not completely cancelled out by having the two cells in adjacent arms, a variable condenser is used to complete the capacitive balance. However, the phase detector used in this circuit is relatively insensitive to quadrature components and hence eliminates the need for a precise capacitive balance.

The oil bath to keep the conductivity cells at a constant and equal temperature consists of a 7-gallon galvanized steel can filled with light

mineral oil. The oil is circulated by means of a stirrer at the bottom of the can and appropriate baffles are provided which cause the oil to flow down the centre of the bath and up the sides. The 500-watt immersion heater is encased in copper tubing and is laid in a circle at the bottom of the can. The cells are mounted on the lucite cover of the bath in a circular pattern and the measuring sections of the cells extend well down into the oil. This arrangement provides for a symmetrical flow of oil past the heater and cells and assures equal temperature distribution throughout the cell area. The temperature of the bath is controlled by a DC thermistor bridge which operates a servo-amplifier and motor. The servo-motor actuates a microswitch in the heater circuit and a variac controls the amount of current fed to the heater. By switching in appropriate resistances in one arm of the thermistor bridge the bath can be run at 30° or 38°C. When stabilized the bath holds temperature to within about $\pm$ ·005°C.

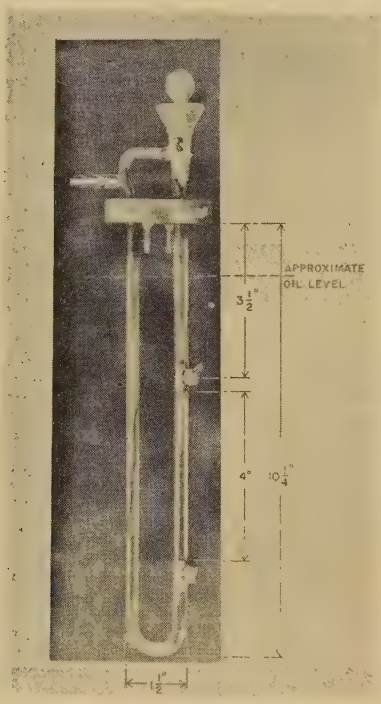

Figure 2. Conductivity cell.

Figure 2 is a photograph of the type of conductivity cell used. The electrodes are platinum foil fused to the inside of the glass tubing. Contacts are made to the electrodes through the sides of the tube and the leads are connected to plug-in terminals on the lucite cell mounting. The tubing between the cell electrodes is made of $\frac{1}{4}$-inch ID precision-bore tubing. The cells have a fluid capacity of about 17 cc., an electrical cell constant of about 30 cm.$^{-1}$, and are as physically similar as practicable.

The electrodes of the cell are platinized to reduce the polarization effects. The procedure of platinizing and initial cleaning was the same as given in REILLY and RAE (1944, pp. 433–4). In use, the cells are cleaned every three or four weeks with sulphuric acid and potassium dichromate cleaning solution.

All the controls which are used during routine operation of the instrument are located on the bridge panel and on the main control panel (see Figure 3). The other controls on the phase detector panel are used only for aligning the instrument and for test purposes. The bottle seen to the left of the table is a water trap used in conjunction with a small vacuum pump for emptying the cells. This pump as well as the stirrer motor, oscillator, power supply, and bridge servo-amplifier are located at the rear of the instrument and cannot be seen in this photograph. The instrument is 3 feet wide, 2 feet deep, and 4 feet high. When used in the laboratory the instrument is on casters, and when operated on shipboard shock mounts are used.

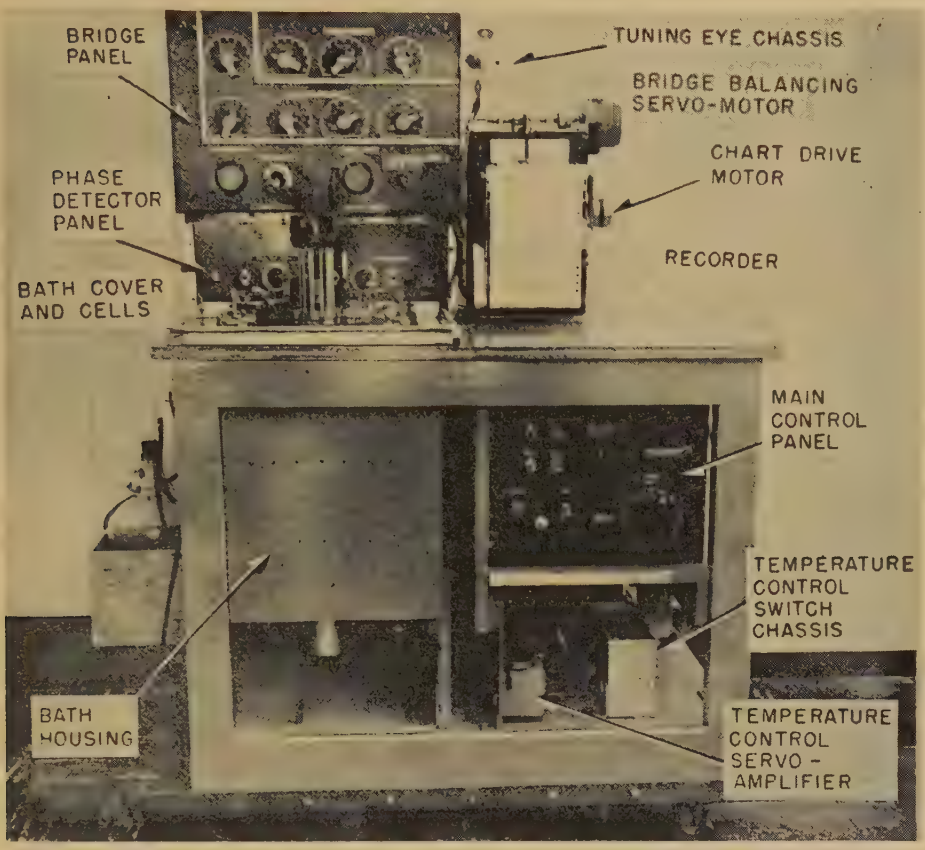

Figure 3. Front view of salinometer.

Operation of Instrument

Before salinities can be determined with the salinometer the Y cell is filled with sea water of about $35\,^0/_{00}$ salinity (its exact value need not be known) and the instrument is standardized. To standardize, the five sample cells are filled with Copenhagen standard water and allowed to come to bath temperature. Each cell in turn is connected into the bridge circuit and the standardizing arm adjusted to make the value of the reading arm correspond to the salinity of the standard according to the empirically determined calibration curve.

The salinities of the unknown samples of sea water can now be determined by filling the sample cells with them and allowing the cells to come to temperature equilibrium. These cells are then connected in turn into the bridge circuit and the standardizing arm set, for each cell, at the value determined for that cell by the standardizing process. The value of the reading arm for each resulting balance of the bridge is converted to salinity units by means of the calibration curve. At the end of the run the standard

is again measured and the data corrected for any drift of the instrument that may have occurred.

If there are many samples to be measured, for which several days will be required, a substandard water may be used most of the time in place of the Copenhagen water. In this case the standard water is used only for the initial standardization and as an occasional check on the substandard water. The sea water in the Y cell is usually not changed until the cells require cleaning.

Theory

Figure 4 is an idealized representation of the measuring bridge of the salinity instrument, with the constant-temperature bath for conductivity cells not indicated. If the resistances Q and Y are left fixed while sea waters of different salinities are placed in the sample cell and allowed to come to bath temperature, and the bridge balanced each time with the resistance P, a relationship between the reading, P_σ, and the salinity σ of the sea water will be determined. The purpose of the following discussion is to derive a simple approximation to this relationship and to bring out some of the principles involved in this method of measurement. It will be shown that a satisfactory approximation has the form $\sigma = \alpha + \beta P_\sigma + \gamma P_\sigma^2$, where σ is the salinity in $^0/_{00}$ and P_σ the reading in ohms; and that once the reading, P_s, corresponding to the salinity S of the standard has been chosen, the relationship is a unique one, independent of Y and Q.

The Y cell contains sea water of salinity approximately $35\,^0/_{00}$ but otherwise unknown. Its presence in the bridge makes the bridge balance relatively insensitive to bath temperature variation and reduces the amount of parallel capacitance across the P or Q resistance arm required for a null balance. By platinization of the electrodes and by use of low wave-form distortion, 1000 c.p.s. power, the series resistance and capacitive reactance associated with galvanic polarization phenomena in the conductivity cells of the bridge have been reduced sufficiently to permit their neglect in the derivation[1]). Also, the cell lead resistances have been found small enough to be neglected. With these things in mind we may represent the bridge as a pure resistance one, in which cell resistances are the resistances of the sea water alone.

Therefore, referring to Figure 4, let

S and σ = the salinity of standard water and the sample water, respectively;

X_s and X_σ = the resistance of the X cell when filled with standard water and the sample water, respectively;

[1]) Much information on the subject of conductivity measurements can be found in a series of papers appearing in the Journal of the American Chemical Society. In particular, two papers of the series that were of special interest and help in connexion with the galvanic polarization phenomenon were:—

JONES, G., and S. M. CHRISTIAN, 1935. "The measurement of the conductance of electrolytes. VI. Galvanic polarization by alternating current." J. Amer. Chem. Soc., 57, pp. 272–280.

JONES, G., and D. M. BOLLINGER, 1935. "The measurement of the conductance of electrolytes. VII. On platinization." Ibid., 57, pp. 280–284.

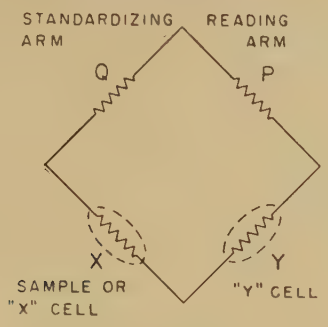

Figure 4. Idealized bridge.

Y = the resistance of the Y cell;
P_s and P_σ = the resistance of the reading arm when $X = X_s$ and $X = X_\sigma$, respectively;
Q = the resistance of the standardizing arm.

The standardization of the bridge against standard water S is made by adjusting Q until the bridge is in balance with $P = P_s$. The bridge relationship for this step is

$$X_s/Q = Y/P_s \tag{1}$$

If the sample cell is then filled with sea water of salinity σ, Q being unchanged, the bridge equation for balance becomes

$$X_\sigma/Q = Y/P_\sigma \tag{2}$$

Combining (1) and (2) we get

$$X_s/X_\sigma = P_\sigma/P_s \tag{3}$$

Since we assume that polarization and cell lead resistances can be neglected, the resistances X_s and X_σ are related to the solution conductivity C_s and C_σ by

$$X_sC_s = K \tag{4a}$$

$$X_\sigma C_\sigma = K \tag{4b}$$

where K is the cell constant of the sample cell.

Substituting equations (4a) and (4b) in (3)

$$C_\sigma/C_s = P_\sigma/P_s \tag{5}$$

With the data of Thomas, Thompson, and Utterback (1934), the salinity versus conductivity isotherm for 25°C. may be represented empirically by the parabola

$$\sigma = a + bC_\sigma + cC_\sigma^2 \tag{6}$$

with an accuracy of $\pm \cdot 002\,^0/_{00}$ in the salinity range of $30\,^0/_{00}$ to $40\,^0/_{00}$.

We assume this is also true for the temperatures of 30°C. and 38°C. at which the bath is operated (but for which no information is available).

Combining (5) and (6), we have

$$\sigma = a + b(C_s/P_s)P_\sigma + c(C_s/P_s)^2P_\sigma^2 = \alpha + \beta P_\sigma + \gamma P_\sigma^2$$

which is the form of the formula approximating the bridge relationship between salinity and reading. The coefficients in this polynomial are found empirically by calibrating the bridge against samples of known salinity (by the method of least mean square). This result gives the information that the bridge calibration depends only on the bath temperature (C_s, b, c depend on temperature) and the reading P_s, chosen to correspond to the standard sea water of salinity $35\,^0/_{00}$. The temperature dependence, however, turns out to be small, a change in bath temperature from 30 to 38°C. modifying the calibration by less than $\cdot 03\,^0/_{00}$ at $30\,^0/_{00}$ and $40\,^0/_{00}$ where the temperature effect is most pronounced.

It can also be seen from the above discussion that the resistance Q of the standardizing arm is a function of the particular X cell and the sea water present in the Y cell, and will have a different value when either of these are changed. For any one combination of them Q will also change slowly with time, due to small changes in the resistance of the Y cell. This drift, however, is not great over a day's time (it varies from ·01 to ·10 ohms, which is at the most equivalent to $0{\cdot}010\,^0/_{00}$) and can be corrected for by checking the bridge before and after each day's run with standard or substandard water.

Precision and Accuracy [1]

The precision of a single measurement for this salinity instrument has two components; (1) the precision of a single measurement for a particular standardization of the bridge, and (2) the precision of standardizing the bridge. A value for component (1) which would include the effects of flushing was obtained from a series of 50 readings, all made for a particular standardization, on sea waters of salinities ca. $35\,^0/_{00}$ and $36{\cdot}5\,^0/_{00}$, alternating in sets of 5 between the two sea waters. The greatest deviations from the average and standard deviation of the $35\,^0/_{00}$ readings were $0{\cdot}003\,^0/_{00}$ and $0{\cdot}001\,^0/_{00}$, respectively, while the corresponding parameters in the case of $36{\cdot}5\,^0/_{00}$ were $0{\cdot}004\,^0/_{00}$ and $0{\cdot}002\,^0/_{00}$. The largest deviation from the average found above gives a value for component (1) of $\pm\, 0{\cdot}004\,^0/_{00}$. Because components (1) and (2) are equal, the precision of a single measurement was taken as $\pm\, 0{\cdot}008\,^0/_{00}$ (with standard deviation $\sqrt{2} \times 0{\cdot}002 = 0{\cdot}003\,^0/_{00}$).

The accuracy of the salinometer, besides depending on the precision, is also a function of the accuracy of the salinities of the calibration samples, linearity errors in the bridge reading arms, the variation of the chlorinity-conductivity relationship at a fixed temperature in the oceans, and the accuracy of the standard water. An estimate of the accuracy of this instrument for a single measurement based on all these factors except the last two comes out to be $\pm\, \cdot 01\,^0/_{00}$, or better, at $35\,^0/_{00}$ salinity, with a linear decrease

[1]) As used here, precision means ± the maximum deviation from the *average* value; accuracy means ± the maximum deviation from the *true* value.

to $\pm$ ·03 $^0/_{00}$, or better, at 30 $^0/_{00}$ and 40 $^0/_{00}$. The above accuracy figure for 30 $^0/_{00}$ and 40 $^0/_{00}$ (and thus the accuracy either side of 35 $^0/_{00}$) is subject to possible improvement by a recalibration based on independent salinity determinations which are of higher accuracy than was available for the present calibration.

Copenhagen normal water has been used as the salinity standard but any other sea-water standard of about 35 $^0/_{00}$ in salinity may be used. In either case, on the assumption that the conductivity-salinity relationship in the oceans is fixed, the above accuracy limits are relative to the accuracy of the standard used. KNUDSEN (1925) does not recommend the use of Copenhagen normal water as a salinity standard in conductivity measurements because of the solution of glass from the walls of the containing ampule over long periods of time. The authors have not been able to find in the literature any estimate of magnitude of the effect of this process on the conductivity of Copenhagen water, although there has been some investigation of, and discussion on, the effect on chlorinity and density (GIRAL, 1926; MATTHEWS, 1926; DEACON, 1933; and KING, 1950).

In an attempt to get some information on the changes of conductivity with time, the authors measured the salinity (with the salinometer) of several ampules of P_{15} (bottled in 1937) after the bridge had been standardized against P_{21} (bottled in 1953). These results were that the conductivity of the P_{15} water was equivalent to that of water of about ·006 $^0/_{00}$ in salinity below the salinity calculated from the chlorinity value stated on the label. On the assumption that the glass in each case dissolves at the same constant rate, the results would indicate that the error involved in using Copenhagen water that is 3 or 4 years old is relatively small. It can also be mentioned that the determinations on deep ocean water made with the salinometer during hydrographic cruises agree to about $\pm$ 0·01 $^0/_{00}$ with the averages of values for the same areas found previously by KNUDSEN titration (compare Figure 5 of this report with Figure 25 of ISELIN, 1936).

Because of these considerations, the use of Copenhagen water seems justified until such time as a more suitable standard for conductivity measurements becomes available.

The balancing mechanism of the instrument will register a change in resistance in an arm of the bridge of less than 0·01 ohms. The reading on the chart can be estimated to 0·01 ohms, which is equivalent to a change in salinity in the "X" cell of about ·0008 $^0/_{00}$ at midscale of the calibration curve. The overall sensitivity of the instrument, therefore, is about ·001 $^0/_{00}$ in salinity, and the measurements obtained are accordingly reported to the third decimal place.

Results of Field Tests

The salinometer has been used on a two months cruise in the Sargasso and Caribbean Seas, during which about 850 salinity samples were measured, a two months cruise in northern waters, during which 450 samples were measured, and a one month cruise in waters west of Bermuda, during which 1358 samples were measured. During these cruises the instrument proved

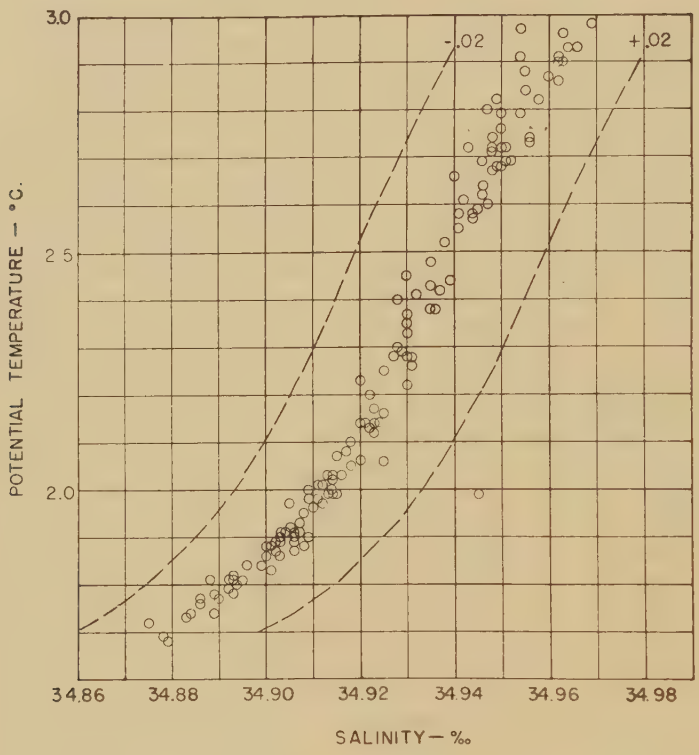

Figure 5. ϑ/S curve in deep water west of Bermuda.
Salinity values obtained with salinometer.

to be seaworthy and unaffected by the rolling, pitching, or vibration of the ship, or the normal frequency and voltage variations of the ship's generator used as power supply.

Although routine measurements were made throughout the cruises some of the techniques associated with the operation of the instrument were improved. Most of these techniques had to do with the handling of the samples before analysis and the filling of the cells; both processes were found to influence greatly the precision of the results. It was found that the samples could be comfortably analysed at the rate of 20 measurements in one hour.

In order to obtain the full advantage of this type of instrument on a hydrographic cruise it may often be desirable to analyse the samples immediately after they are obtained. This would allow the oceanographer to make decisions as to bottle spacing, locations, etc., of the next station so as to obtain the greatest benefit from the cruise. From the experience gained on these first cruises it was found that the greatest factor affecting the time span between sample gathering and analysis was the need to warm the cold samples to room temperature before putting them in the cells, for

otherwise the excess dissolved gases released as the sample water warmed up formed small bubbles in the cell, which caused errors. Since immediate results were not required on the cruises this difficulty was easily overcome by allowing the samples to stand in a warm place for 12 to 24 hours before analysis. Any future instrument of this kind should perhaps be supplied with a refrigerated bath so that the samples could be analysed at a lower temperature, without the necessity for this prewarming.

On these past cruises all final salinity values were determined before the ships docked. During the second cruise, spot checks were made by filling more than one cell with the same sample at the time the sample bottle was first opened. There were 65 checks made in this way and in all cases the salinity values obtained from each of these checks differed by no more than 0·01 $^0/_{00}$, the great majority (90 %) differing by 0·005 $^0/_{00}$ or less. These results agree favourably with the values obtained by earlier determinations of precision made in the laboratory and already referred to.

Some of the data from the third cruise are presented in Figure 5. This figure shows the ϑ/S correlation in the deep waters (below about 2500 metres) west of Bermuda. At these depths great variations from the average ϑ/S correlation curve are not expected. The band formed by the dotted lines on either side of the points represents a total salinity spread of 0·04 $^0/_{00}$, the narrowest spread one might expect from titration.

The curve represents all the data (taken below a potential temperature of 3·0°C.) of 33 different stations. The stations were made over a period of 21 days and the salinity determination for each station made within about 24 hours of gathering the samples.

The cruises so far made have shown the practicality and general seaworthiness of the present instrument. As mentioned earlier, it seems likely that a new calibration, based on more accurate, independently determined, salinity points would improve its accuracy, particularly at the extremes of its calibrated range. Also, there are several improvements which could be incorporated in a future design which would increase the instruments versatility and ease of operation. However, it is felt that the instrument as it now stands satisfies a need for a quick and accurate method of measuring salinity on shipboard and, as such, should be useful in this phase of oceanographic work.

Acknowledgements

The authors wish to thank the various personnel of the Woods Hole Oceanographic Institution who with their advice and help contributed much towards the construction of this instrument. Special thanks are due to Mr. Allyn C. Vine, whose overall direction was most helpful, especially in formulating the requirements of the instrument as a useful sea-going tool, and to Mr. Floyd Soule for the many discussions with him on the Coast Guard unit; to Dr. John Kanwisher for the design of the phase detector; to Mr. Paul Bennett for help with the electronics involved; and to Mr. Valentine Worthington for his encouragement and enthusiasm, and his endeavours to use the instrument to its fullest capabilities.

Summary

A new sea-going conductivity bridge (salinometer) for measuring the salinity of sea water is described. In principle, the salinity of an unknown sample is determined by comparing its conductivity with that of a sample of known salinity at the same temperature. The calibration of the bridge is found empirically.

The instrument consists of a constant-temperature bath, a 1000-cycle impedance bridge with glass conductivity cells in two of its arms, a phase detector to convert the 1000 cycles output of the bridge to DC, and a balancing mechanism to complete automatically the "fine" adjustment in bridge balance. It operates from a 110 v. 60-cycle power source.

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The Enumeration and Collection of Marine Phytoplankton[1]

By

Robert W. Holmes and **Theodore M. Widrig**[2])

Introduction

Ecologically speaking, we recognize two general types of descriptive phytoplankton investigations—the general survey and the time-area study. Perhaps the more common is the former, usually considered to be essentially synoptic, in which the areal distributions of species and populations, or plant pigments, are described and frequently related to physical, chemical, and biological parameters (see, for instance, BRAARUD, GAARDER, and GRØNTVED, 1953; GRAN, 1929a; or STEEMANN NIELSEN, 1934). Time-area studies concern fluctuations in abundance of species, populations, or pigments, at one or more locations with respect to time. Such fluctuations are frequently correlated with variations in conservative and non-conservative properties of the environment (see, for instance, GAARDER, 1938; GRAN, 1929b; HALLDAL, 1953; HOLMES, 1956; RILEY, 1946; or STEEMANN NIELSEN, 1951). The correlations and conclusions in many such studies have been made by the inspection of numerical data and graphs. To employ such techniques is to assume that the probability of the observed correlation being due to chance is insignificantly small. In many instances this has apparently been true, but uncertainty as to the validity of conclusions will always remain until some objective, quantitative estimate of error can be determined. If the probable-error concept, in one form or another, had been employed, considerable strength would have been added to the conclusions.

Since comparisons and correlations in such ecological studies frequently involve the abundance of phytoplankton as one parameter, it was decided

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[2]) Of the Scripps Institution of Oceanography, La Jolla, and the U.S. Fish and Wildlife Service, La Jolla, respectively.

to employ statistical methods to study the precision of a phytonplankton enumeration technique and to evaluate the adequacy of sampling as it is normally carried out. Certain concepts emerge from these studies which will be of aid in deciding how best to sample marine phytoplankton.

Enumeration

It is not our purpose to discuss the relative merits of various counting techniques; instead, we propose to investigate the precision of one of the most commonly employed techniques—the sedimentation method of UTERMÖHL (1936). This technique involves the estimation of phytoplankton abundance in an unconcentrated water sample by the enumeration of organisms contained in one or more aliquots of that sample. This is accomplished by pouring aliquots from a well agitated sample into volumetric cylinders, allowing the organisms to settle, and counting them with the aid of the inverted microscope.

The essential problem in evaluating such a method is to determine whether the organisms in the aliquot have been selected at random and are counted without bias (in the statistical section that follows these two sources of error are undifferentiated). Once the degree of contagion ("clumping") is known for a species, it is possible to assign limits to the probable number of that species contained in the original sample. The inquiry was made in

Table 1

	Volume of aliquot (ml.)	Number of aliquots counted	Total number of organisms counted	Average number in each aliquot	Variance s^2	$\left(\frac{s^2}{\bar{x}}\right)$	Estimated λ^2
Ceratium furca	2	20	226	11·30	6·54	0·58	Negative
– –	10	–	989	49·45	27·00	0·55	–
Ceratium fusus	2	–	106	5·30	3·91	0·74	–
– –	10	–	501	25·05	42·36	1·69	0·028
Ceratium tripos.....	2	–	1435	71·75	57·78	0·81	Negative
– –	10	–	6501	325·05	243·94	0·75	–
Dinophysis caudata....	2	–	280	14·00	23·58	1·68	0·049
– –	10	–	1288	64·40	181·62	2·80	0·028
Peridinium Stenii	2	–	164	8·20	5·75	0·70	Negative
– –	10	–	669	33·45	72·05	2·15	0.035
Prorocentrum micans ..	2	–	2	0·10	0·09	0·95	0·001
– – ..	10	–	13	0·65	0·66	1·01	0·001
Radiolarian sp.....	2	–	17	0·85	0·55	0·65	0·001
– –	10	–	75	3·75	3·25	0·87	0·001
Chaetoceros borealis f. *concavicornis*	2	–	10	0·50	0·90	1·79	0.001
– – –	10	–	16	0·80	0·38	0·47	0.001
Nitzschia seriata.....	2	–	182	9·10	43·57	4·79	0·62–0·72
– –	10	–	591	29·55	194·94	5·07	0·19
Thalassiosira gravida ..	2	–	22	1·10	4·73	4·30	6·7–8·9
– – ..	10	–	27	1·35	6·87	5·09	10–11

the following manner. A phytoplankton sample was collected with a No. 20-mesh silk net, preserved, diluted to 1500 ml., and placed in a 2-litre boiling flask. After thorough agitation of the flask, samples were poured into a 2 ml. and a 10 ml. volumetric counting cylinder, allowed to settle, and counted[1]). This was repeated until a total of twenty 2 ml. and 10 ml. aliquots had been counted (see Table 4). Of the species present in the aliquots only ten were chosen for enumeration—six dinoflagellates (*Ceratium furca*, *C. fusus*, *C. tripos*, *Dinophysis caudata*, *Peridinium Stenii*, and *Prorocentrum micans*), a radiolarian (which could not be identified by species but which belongs to the sub-order Acantharia), and three diatoms (*Chaetoceros borealis* f. *concavicornis*, *Nitzschia seriata*, and *Thalassiosira gravida*).

The hypothesis that the individual organisms were selected at random (and counted without bias) was considered not false, with a probability of 0·95 that the decisions were correct, if the value of the quantity $\frac{s^2}{\bar{x}}$ fell at or below 1·6 for the 20 samples[2]). An examination of the value of this quantity (Table 1) reveals that the organisms differed from one another in their degree of contagion in the cylinders; *D. caudata*, *N. seriata*, and *T. gravida* required the rejection of our hypothesis in both the 2 and 10 ml. aliquots; *C. fusus*, *P. Stenii*, and *Ch. borealis* f. *concavicornis* required that our hypothesis be rejected in either the 2 ml. or 10 ml. aliquots; and finally *C. furca*, *C. tripos*, *P. micans*, and the radiolarian did not require the rejection of the hypothesis.

In those instances in which our hypothesis is not in doubt, it becomes a simple matter to assign upper and lower limits to the probable number contained in the original sample from the number counted in the aliquot. We presume that the organisms in the aliquots are distributed in the Binomial frequency function. To facilitate such determinations, two graphs have been prepared (Figs. 1 and 2) from data based on the work of W. L. Stevens and presented by Fisher and Yates (1949)[3]). Upper and lower expectation levels can also be determined for organisms that required the rejection of our hypothesis in both aliquots. These species occurred both as single cells

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[1]) After counting, the material contained in the cylinders was discarded, in as much as it could not be returned quantitatively to the boiling flask.

[2]) In this paper the following symbols are defined as follows:—
s^2 is the estimated variance,
σ_x^2, the limit of s_x^2 as N goes to the population size,
x, the sample count,
$\bar{x}$, the arithmetic mean,
N, the number of samples.
The expected value of s^2, if the hypothesis were true, was taken as $\bar{x}$. The ratio s^2/x should then be distributed as $\frac{\chi^2}{N-1}$, with N-1 degrees of freedom; $\chi^2/19$ for 19 degrees of freedom is approximately 1·6.

[3]) The curves in these graphs give the upper and lower numbers that would be contained in the sample for a given aliquot count for 95 % confidence. These limits are appropriate when the volume of the organisms contained in the aliquot is very small in proportion to the total volume of the sample—which is the case when unconcentrated water samples of moderate size (greater than about 100 ml.) are used. The limits are conservative if this proportion is not small.

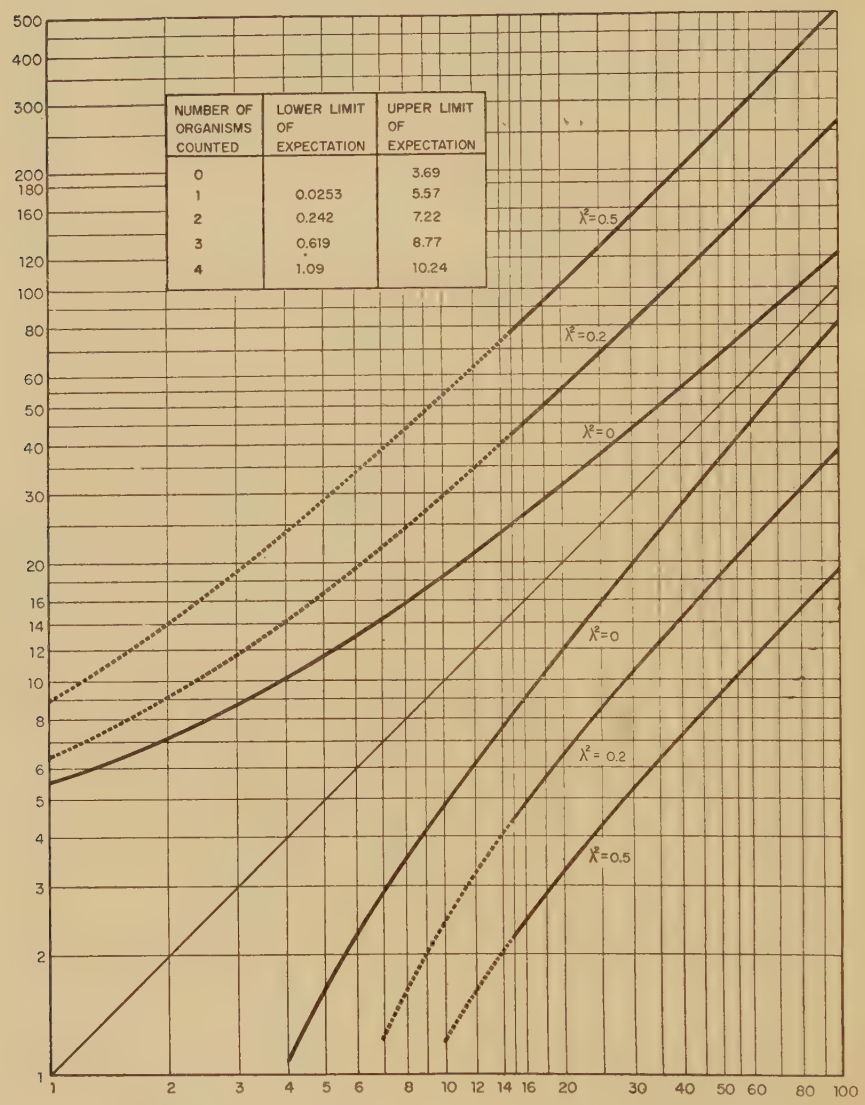
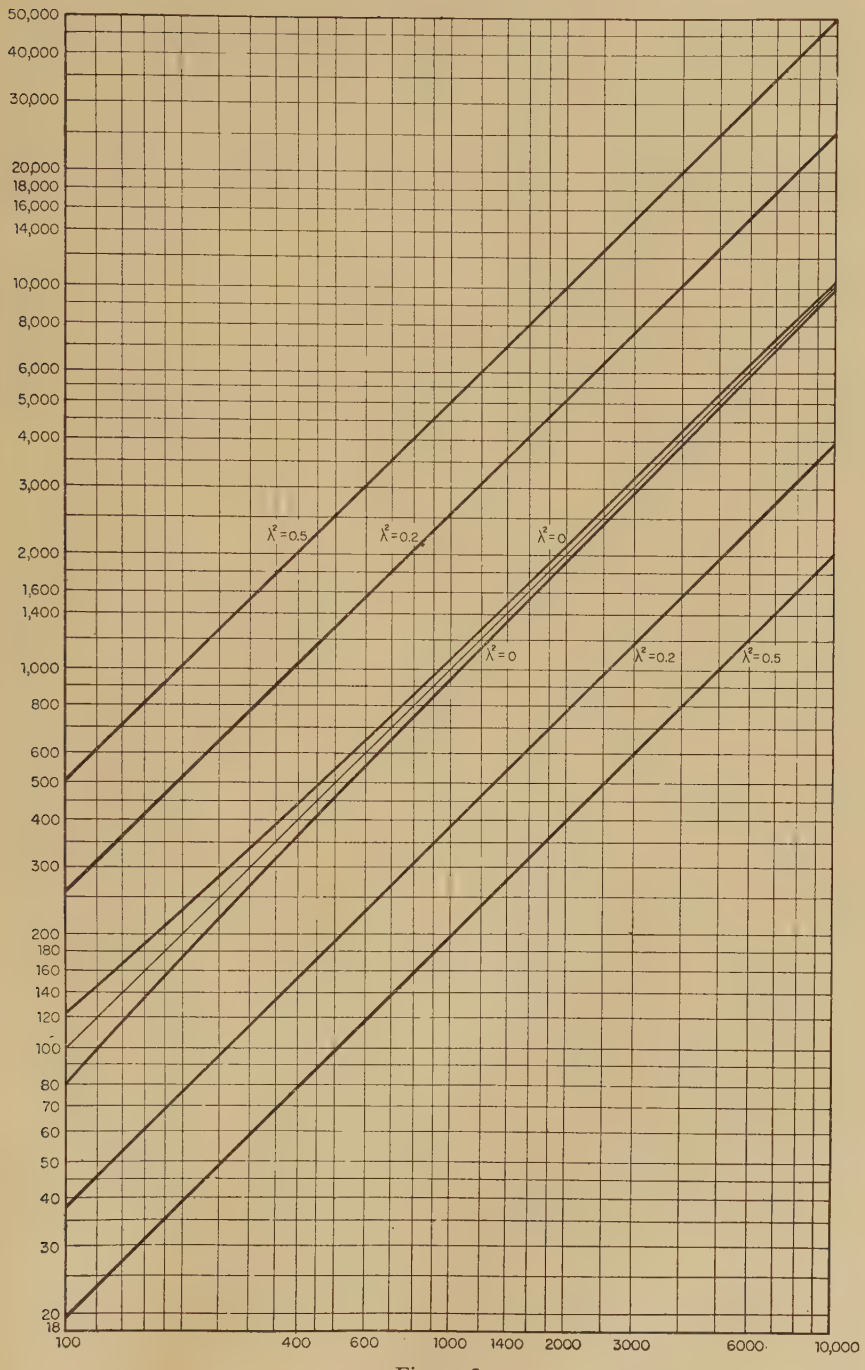


Figure 1. The limits of expectation for Binomial and Poisson distributions at a 95% level of confidence for 3 degrees of contagion ($\lambda^2 = 0$, $\lambda^2 = 0{\cdot}2$, $\lambda^2 = 0{\cdot}5$). N from 0 to 100.

Figure 2. The limits of expectation for Binomial and Poisson distributions at a 95% level of confidence for 3 degrees of contagion ($\lambda^2 = 0$, $\lambda^2 = 0{\cdot}2$, $\lambda^2 = 0{\cdot}5$). N from 100 to 10,000. ——→


50,000
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80
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60
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40
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20
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100
400
600
1000
1400
2000
3000
6000
10,000
λ²=0.5
λ²=0.2
λ²=0
λ²=0
λ²=0.2
λ²=0.5

Figure 2.

and in groups of two or more cells singly and in pairs in the case of *D. caudata*, and singly, and in chains of two or more individuals in *N. seriata* and *T. gravida*. This means that our hypothesis needs to be rejected because of their high degree of contagion in the original sample, even though the sample was thoroughly shaken before aliquots were taken. Such clumped organisms, under some general assumptions, can be expected to follow the Negative Binomial frequency function. The degree of contagion will be described by the coefficient

λ^2, in $\sigma_x^2 = x + \lambda^2\bar{x}^2$, or by k, in $\sigma_x^2 = x + \frac{\bar{x}^2}{k}$: the greater the degree

of contagion the higher the value of λ^2. Methods for the calculation of k are given by ANSCOMBE (1949), and BLISS and FISHER (1953). The approximate value of λ^2 is given in Table 1 for each species in each of the two aliquot volumes. Unfortunately the efficiency of the estimation of λ^2 varied, because three methods of calculation were employed, the choice depending upon the number of organisms counted and the value of λ^2; the tendency toward contagion in one aliquot but not in the other must be ascribed to chance. In actual practice it is probably reasonable to assume the Binomial distribution when $\frac{s^2}{\bar{x}}$ somewhat exceeds 1·6, providing λ^2 remains low—

the estimated precision will be only slightly too great. In this paper a value of λ^2 equal to or less than 0·05 is considered the critical point of departure from the Binomial frequency function. However, when the degree of contagion is marked (greater than 0·05, by definition), it should not be ignored. In Figures 1 and 2 limits of the expectation for values of λ^2 of 0·2 and 0·5 are given[1]). Regardless of the number counted in the aliquots, these curves reveal the difficulty of obtaining accurate estimates of sample abundance with these clumping species, even with λ^2 as low as 0·05. A truly precise estimate of such clumping species can be obtained only by counting all such organisms in the entire sample. With different species of the chain-forming type, the degree of contagion can be expected to vary. This variation reflects the constancy of the number of cells within each chain. Thus, if the numbers vary only slightly from chain to chain, as was the case with *D. caudata*, then the degree of contagion is less than if the numbers per chain vary considerably, as was the case with *T. gravida*. *N. seriata* in this instance fell in between these two extremes. This reasoning implies that we believe the chains themselves to be sub-sampled randomly. We believe this to be the case even though the evidence is indirect. Prof. J. NEYMAN has pointed out (personal communication) that there is a very good possibility that this is indeed the case. It should be pointed out that a summation of the number of occurrences of a few or of many species in one or more aliquots of a sample does not yield a very precise estimate of

[1]) The limits were calculated with the following expression (after ANSCOMBE, 1949):—

$$\left[\text{antilog}_{10}\left[\log_{10}\left(\text{count} + \frac{1}{2\lambda^2}\right) \pm 2\sqrt{0{\cdot}1886\ \text{trigamma}\left(\frac{1}{\lambda^2}\right)}\right]\right] - \frac{1}{2\lambda^2}$$

the total abundance of such species in the sample if the proportion and/or abundance of clumping species is large.

Most marine phytoplankton species are not chain-forming, but unfortunately many important genera and species do exhibit the chain-forming habit (for instance, *Chaetoceros*, *Rhizosolenia*, *Thalassiosira*, *Nitzschia*, etc.). Thus the estimation of sample abundance may or may not be difficult with the UTERMÖHL technique, the degree of difficulty depending upon the composition of the sample.

In this study all but two of the species investigated were considered to be randomly sampled, even though two of these showed slight contagion[1]). In addition to providing useful information about limits of expectation for aliquot counts, Figures 1 and 2 also show that it is advisable to count, if possible, at least between 15 and 30 representatives of any of the non-clumping species, as the percentage error of the estimate increases rapidly as the count falls below this region. This is not necessarily the case with clumping species (see Figs. 1 and 2).

The Comparison of Samples from Different Areas

Once we are able to determine upper and lower limits of expectation of a count, we can decide objectively when differences exist between samples. *Such differences are appropriate only to the sample, however, and if we wish to consider our sample as representative of an area of the sea or any volume larger than the sample volume, the situation is quite different.* In considering sample attributes to be areal attributes, we must consider additionally how well one or more samples characterizes the larger region.

This problem was approached in a manner similar to that employed in the enumeration section. It was deemed necessary to determine, first, whether or not the phytoplankton are generally distributed according to the Binomial frequency function or are contagious. Once this is known, it is possible to estimate the degree of contagion, if any, and under some general assumptions determine how great the differences between samples need be before they can be considered significant.

Data from two different sources have been employed in this particular study. In the first example the phytoplankton samples were collected in the Channel Island area off southern California by vessels and personnel of the California Co-operative Oceanic Fisheries Investigations during the first five months of 1953. The samples were collected at approximately bi-monthly intervals in Nansen bottles at 10 m. depth at four stations roughly 20 miles apart lying along a N.E.–S.W. line approximately midway between Santa Cruz and San Nicolas Islands. Of the species present in this material, several were arbitrarily selected for study (see Table 2); of these, *Pontosphaera Huxleyi* and *Nitzschia seriata* and the composite group Gymnodiniaceae were thought to be ubiquitous. The value of λ^2 is given for all the species,

[1]) In the material employed in this study it so happened that *Ch. borealis* f. *concavicornis* occurred only as individuals and in pairs. This is surprising and is not generally the case with this chain-forming species.

Table 2

	Σx	Zeros	$\bar{x}$	s^2	$\frac{s^2}{\bar{x}}$	Estimated λ^2
Exuviaella baltica	55	9	2·037	10·96	5·380	1·0–1·1
Gymnodiaceae	335	0	12·407	86·37	6·961	·357–·435
Pontosphaera Huxleyi	1433	0	53·074	2221·14	41·850	·625–·715
Nitzschia seriata	893	2	33·07	2171·92	65·68	1·67–2·5
Pennate diatom	66	10	2·444	16·41	6·71	1·6

N = 27

but for only two (*Pontosphaera Huxleyi* and the composite group, Gymnodiniaceae) were the limits of expectation calculated, since these alone satisfied ANSCOMBE's (1949) conditions (a mean greater than 15 and λ^2 between 0·2 and 0·5). It should be remembered that the value of λ^2 is an estimate of the total degree of contagion—both that in the aliquot and that within the sea. We believe that in the case of *Exuviaella baltica*, the Gymnodiniaceae *Pontosphaera Huxleyi*, and the pennate diatom the aliquots were randomly chosen, since they are not chain-forming organisms (see p. 27), and therefore that the value for these is truly an estimate of the degree of contagion that they manifest in the sea. *Nitzschia seriata*, on the other hand, is not randomly sub-sampled in the procedure for taking aliquots (see p. 23) and the value for λ^2 is difficult to interpret. As expected, the degree of contagion is higher when the effects of taking aliquots and the distribution in the sea are combined than when only the contagion exhibited in taking aliquots is considered. However, the actual amount of contagion due to distribution in the sea was not evaluated; it is certainly lower than 1·67–2·5.

An inspection of the values of λ^2 (Table 2) for the different groups leaves little doubt that under the conditions of the test, the organisms were not distributed at random. If they followed the Negative Binomial frequency function, the difference in precision of sample counts, which depends on the degree of contagion, can be seen from a glance at Figures 1 and 2. While we cannot at present give the limits of expectation for a value of λ^2 greater than 0·5 there is no doubt that they are much more extreme than those given for $\lambda^2 = 0{\cdot}5$ (Figures 1 and 2). Under the conditions of this test, even with cosmopolitan species, the differences in abundance that are required for significance, when a single sample from each area serves as the basis for comparison, are so great that only the crudest comparisons are possible.

In the second example we have employed some of the results of a study made by HASLE (1954) in Oslo Fjord. In this instance the methods of enumeration were identical with ours; only the area and sampling plan were different. HASLE collected four surface water samples at each of six stations during the same day in the middle of that portion of the fjord lying westward of and between Moss and Fredrikstad. Two samples were taken 25 m. apart 100 m. to the west of the fjord centre and 25 m. apart 100 m. to the east of the centre of the fjord. This sampling plan was repeated six times at 5 Km. intervals along the major axis of the fjord. Thus, in all, 30 samples were collected. The results of analysis of these data are presented in Table 3.

Table 3

	Σx	$\bar{x}$	s^2	Estimated λ^2
Ceratium furca	1828	76·17	1156·6	0·19
Ceratium fusus	516	21·50	209·6	0·41
Dinophysis acuta	1406	58·58	955·4	0·26
Dinophysis borealis	787	32·79	446·8	0·38
Goniaulax polyedra	1574	65·58	1543·2	0·34
Prorocentrum micans	15596	649·83	151157·8	0·32

When compared with the previous example (see Table 2), the results of this analysis reveal a lower and generally more consistent degree of contagion. None the less, contagion still exists. Unfortunately the comparison between these two sets of data cannot be rigorous. However, these data do illustrate the fact that contagion exists in two differing sets of circumstances. The Oslo Fjord data also show that the clumps are small and probably closely spaced.

These data pose many problems, some of which are under study. For the present we merely wish to indicate that contagious distributions are probably quite common in the sea, and to examine the consequences of such distributions with respect to the comparison of samples and the design of sampling programmes.

These data reveal that tests of comparisons between phytoplankton and environmental attributes, or between populations, should be made with the transformed plankton abundance measure, i. e., $\log_{10}(n + \frac{1}{2}k)$. This transformation changes the sampling distributions of organisms in the Negative Binomial into nearly normal distributions. While the tests must be made with reference to the transformed data, conclusions are more intuitively meaningful if the raw data equivalents of the transformed means, variances, and confidence limits are also stated. For purely descriptive purposes, only the re-transformed statistics are necessary. Even though the re-transformed means, for example, are different from the raw data means, the former have properties that make them more representative of the populations than the latter. Again, the confidence limits in terms of the re-transformed data are not equidistant from the means; none the less they accurately describe a region within which the true mean should be expected to fall.

The recognition of contagion along with some idea of its degree has an obvious implication; with only a single sample in an area one cannot describe a population very accurately, either with respect to composition or abundance. Similarly, for a difference between two areas to be significant it often needs to be based upon the examination of more than just two samples. Thus, if we wish to characterize an area, we must take more than one sample at random from within that area. In general, the precision of a population estimate increases in proportion to the square root of the number of samples; an estimate in an area would be 4 times better if we used 16 randomly spaced samples. The limits of expectation decrease for a given degree of contagion when more than one sample is counted; in the above example, the limits of expectation are decreased by $\frac{1}{4}$ of that given for a single estimate for the same value of λ^2. Fortunately for the investigator,

Table 4

Number of individuals counted in the 2 ml. aliquots

Aliquot No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Genus and species																				
Ceratium furca	16	13	9	8	9	10	8	10	11	10	8	14	12	10	10	14	16	13	11	14
Ceratium fusus	7	6	8	1	6	7	7	4	3	6	3	6	2	6	8	7	6	4	5	4
Ceratium tripos	72	72	75	66	55	74	66	74	70	70	82	77	63	62	64	75	77	74	88	79
Dinophysis caudata	10	12	19	15	8	16	12	22	14	12	19	11	12	3	9	14	18	14	23	17
Peridinium Stenii	15	7	10	9	9	6	8	8	6	13	6	7	10	7	7	6	7	8	6	9
Prorocentrum micans	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Radiolarian	1	1	1	2	1	3	0	0	0	0	1	1	0	1	1	0	1	1	1	1
Chaetoceros borealis f. *concavicornis*	0	0	4	0	0	0	0	1	0	0	0	0	1	1	0	1	1	1	0	0
Nitzschia seriata	12	12	15	9	6	5	10	12	26	13	14	0	0	18	1	3	11	2	7	6
Thalassiosira gravida	0	3	0	0	2	0	4	0	0	0	0	0	0	7	0	0	0	0	6	0

Number of individuals counted in the 10 ml. aliquots

Aliquot No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Genus and species																				
Ceratium furca	52	57	48	49	52	45	53	49	45	45	41	52	48	58	51	40	40	42	56	53
Ceratium fusus	35	26	19	20	37	21	30	22	27	15	32	27	29	28	23	15	28	13	28	26
Ceratium tripos	300	333	312	345	343	339	336	332	336	337	329	330	326	305	347	326	301	304	313	307
Dinophysis caudata	53	61	54	73	72	69	57	64	66	62	69	54	99	48	63	54	78	91	50	51
Peridinium Stenii	33	37	39	34	35	29	30	27	34	43	41	59	31	19	27	36	37	28	25	25
Prorocentrum micans	0	0	1	0	0	1	0	1	2	1	2	1	0	0	0	0	1	0	1	1
Radiolarian	5	2	4	0	3	3	6	4	3	4	5	4	4	3	7	2	3	1	5	7
Chaetoceros borealis f. *concavicornis*	0	0	2	1	1	1	1	1	2	1	0	1	0	1	0	0	1	1	1	1
Nitzschia seriata	9	30	21	33	32	37	37	25	48	47	36	37	55	21	27	18	8	21	27	22
Thalassiosira gravida	0	0	0	0	5	0	0	0	5	0	0	0	0	0	8	0	7	0	0	2

the enumeration of additional samples need not take more time; the samples can be combined and counted as one, and the precision of the estimate still increases with the number of samples. More of the ship's time would be required of course for the additional collections. An integrating sampler[1]) designed to be towed behind a vessel would resolve, to a great extent, the demand for extra time. The depth sampled by such a sampler need not be restricted to the surface; by the use of the cable depressor (U.S. Pat. No. 168999) depths down to about 50 m. can be conveniently sampled with the vessel travelling at a speed of about 8 knots.

Summary and Conclusions

1. The precision with which marine phytoplankton abundance can be estimated in a sample by the UTERMÖHL sedimentation method was investigated. In general, aliquot parts of non-chain-forming species and species which occur as individuals, or together as pairs of individuals, are selected at random from the sample by the procedure described and are counted without bias. The degree of precision of the estimate of sample abundance is a function of the number of organisms counted in the aliquot. It is suggested that a minimum of 15–30 specimens of any one organism be counted if possible. The individuals in the chains of chain-forming species, on the other hand, are not selected at random when aliquots are taken, and while the accuracy of the estimate also increases with the number of organisms counted, it does so at a much slower rate. The best estimate of the abundance of such species can only be obtained by counting all the individuals in the entire sample.
2. A method is used which permits the calculation of the limits of expectation for an aliquot count with varying degrees of contagion. A graph is also presented which facilitates such determinations, once the degree of contagion is known.
3. The distribution in nature of a few species of phytoplankton was investigated. These species were found not to be distributed at random. Such inhomogeneity makes it unrealistic to consider sample attributes as precise estimates of areal attributes. If we desire to characterize an area accurately with respect to phytoplankton content and abundance, and then to compare this area with another, more than a single sample

[1]) An integrating sampler, designed to work under these conditions, has been designed and built at the Scripps Institution of Oceanography with financial aid from the Bureau of Ships (Contract NObsr-43356, NE-120221-6). (See Progress Report on Oceanographic Instrumentation, April-June 1953, University of California, Scripps Institution of Oceanography, August 15, 1953.) Several field trials have been made and the instrument has apparently operated satisfactorily, although statistical studies designed to test its efficiency have not been completed.

As the device moves through the water a propeller-driven pump removes a charge of distilled water from behind the free-moving piston and sea water enters through a narrow orifice in the instrument's head. The piston's rate of travel is determined by the sampler's rate of travel through the water. Since an infinite number of samples are collected, the sample is fully representative, and yields a good estimate of the average condition along the line traversed.

from each area must be employed. Fortunately for the investigator, the enumeration of additional samples need not occupy additional time, since the samples may be quantitatively combined with one another before enumeration, or, alternatively, some type of integrated sample might be collected while the vessel is under way.

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The Island Mass Effect

By

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MANY observers, beginning at least with GRAN (1912) and LOHMANN (1912), have reported that as the continental margins of oceans are approached the standing crop of plankton increases. GRAN (1912: 378) estimated the standing crop to be about 100 times greater near shore than it is off shore. These increases have been related by GRAN, LOHMANN, and other authors variously to upwelling, to nutrient-rich run-off water, to the nature of the variations (e. g., salinity) in the particular waters, and to attenuation in a shore population carried off shore.

The same increases are presumed to exist with nearness to island shores, though little attempt has been made heretofore to demonstrate this. For various reasons some explanation for this phenomenon near small oceanic islands seems necessary other than the above. Around islands, such as those of the Hawaiian group, only a relatively small amount of vertical mixing of the passing waters has been reported. Since the areas studied by MCGARY (1955) showed little and were the areas where a significant amount of vertical mixing was anticipated, we are led to say little is expected. While some run-off water could be expected around high islands there would be little or none around low islands. A small amount of percolation water could be expected from any freshwater lens present in the latter case. There would be expected some, though little, variation in salinity outside Kaneohe Bay with distance off shore.

One explanation has been offered (DOTY, 1954: 6 ff.) in relation to atolls which could be expected to apply to reef-surrounded high islands as well. This hypothesis is, in brief, that the benthic algae, including both the endozoic species and those which form calcareous reef margins, accumulate inorganic nutrients from the passing waters, which are relatively poor in nutrients. They would also concentrate these materials from leaching of the freshwater lens and from whatever run-off water there might be. These nutrients would become available to planktonic forms, through for instance, benthotrophic herbivores.

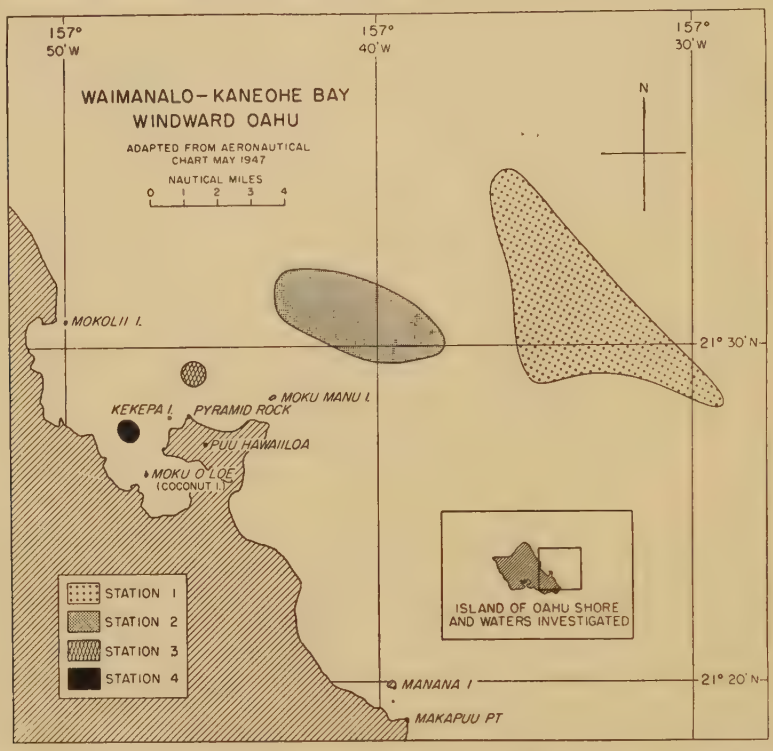

Figure 1. The four classes of positions, called stations, from which water samples were obtained for the present study. The inset shows the area of the large figure in relation to the whole island of Oahu, one of the Hawaiian Islands.

If there is an accumulation of material by such algal organisms, it follows that as island masses are approached there may be either an increase in the size of the standing crop of phytoplankton, or an increase in rate of anabolic activity, i. e., higher productivity, or both. There seem to be no studies of productivity and little information to show the quantitative nature of the reputed or expected increase in standing crop as island shores are approached.

In order to test the hypothesis that there is an increase in productivity as the shore of an oceanic island is approached, and to determine something of its magnitude, water samples were obtained from a series of stations (Figure 1) near the island of Oahu in the Hawaiian chain. These stations were on the windward side of the island in Kaneohe Bay and along a course approximately 60° from the south-eastern entrance to this bay. The samples were obtained by pumping sea water with a cast-iron pump through a plastic hose into a plastic bucket or by dipping water from the sea with a plastic bucket. These stations were occupied during 19 cruises spaced over a period of 14 months.

Salinity, inorganic phosphate-phosphorus, Secchi disk readings, and temperature information were obtained from the various stations. Plankton

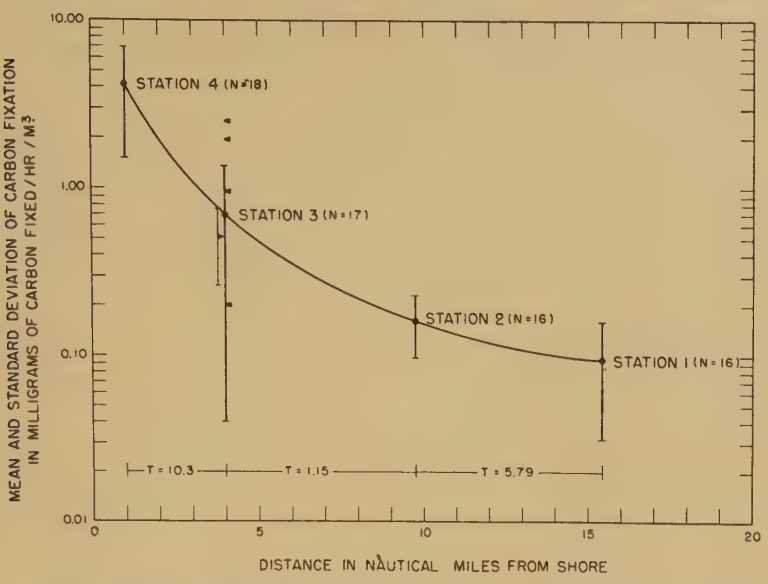

Figure 2. Ability of the waters near the windward shores of Oahu to fix carbon photosynthetically, plotted as a function of distance from shore.

tows, surface-water oxygen content and other data were gathered less regularly as well. Various factors prevented our obtaining samples consistently from below the surface during most of the 14-month study period.

A modification of the dark and light bottle carbon fourteen technique employed by STEEMANN-NIELSEN (1952) was used to determine photosynthetic carbon fixing potential in the samples. A known uniform amount of carbon fourteen, as sodium carbonate, was added to each 276 millilitre pyrex bottle of the sample water immediately after the water had been dipped or pumped aboard. This amount was such that with our counting apparatus the total carbon fourteen count per bottle was at least $2{\cdot}18 \times 10^6$ counts per minute and in most cases more. The inoculated bottles were exposed to light from daylight fluorescent tubes, the intensity of which was about 1500 foot-candles in the live well of the University of Hawaii research vessel, the "Salpa". Sea surface water was circulated through the live well constantly, and it was determined that operationally no elevation in temperature took place above that of the sea surface water. A usual incubation time was 5 hours.

Detailed descriptions of this carbon fourteen technique and the raw data will be distributed for an indefinite period of time in mimeographed form upon request.

For the purposes of this paper, which is concerned with comparative rather than absolute measurement, only the calculated amounts, in milligrammes, of carbon photosynthetically fixed per cubic metre of surface water per hour are presented in Figure 2. Since the results were obtained under operationally uniform conditions, we believe that they reliably reflect

the carbon fixing ability of the local water masses from which they were drawn. The ranking of the results of the stations in relation to each other was consistent on the different cruises. This further induces faith in the significance of the results obtained.

If one omits the two highest values obtained among the seventeen otherwise used in calculating the mean and standard deviation presented for Station 3 in Figure 2, one obtains the mean and standard deviation indicated by the lighter line to the left of the longer vertical bar. The position of each of these high figures, the next lowest figure, and the very lowest figures obtained are indicated by triangles pointing to the left along and above the vertical bars at Station 3. Between the two lowest left-pointing triangles there are thus 15 figures (inclusive of the triangles themselves) and it is the values of 13 of these that we have used as the basis for the lighter line to the left, indicating their standard deviation; the right-pointing triangle indicates their mean.

An examination of the differences between the means obtained indicates a probability that they are reliable as plotted. To this end the T-values between the means have been entered on the figure. The statistical similarity between Stations 3 and 2 is interpreted as an indication that the water at Station 3 is representative of an intermediate condition between reef water and the hardly-reef-influenced but near-shore water of Station 2. That even omission of the two highest figures from Station 3 makes little difference in the picture enhances our confidence that there is a steady elevation in productivity as Station 3 is approached from off shore.

From other evidence it appears that the two high figures (in Fig. 2) may have been due to unusually highly productive water masses which had come out of Kaneohe Bay and still remained undispersed when they were sampled at Station 3. These numbers were obtained shortly after the close of periods of considerable freshwater run-off into the bay. Although we have been gathering information on the effects of run-off water, they are too incomplete to take up here.

From the consistent increase in carbon fixation as shore is approached we infer continued tenability of, and accept as a working theory, the hypothesis that productivity is greater as one approaches an island shore. From our results (Fig. 2) it can be seen that productivity increases at least two orders of magnitude as shore is approached and one passes into Kaneohe Bay, for in the shallow water of inshore stations the as yet unassayed benthic productivity seems to do more than make up for the loss in the depth of the productive column. We are not yet able to assess clearly the effects of the bay. Data from a few cruises approaching Pearl Harbor, on the leeward side of the island, give us results similar to those presented in Figure 2. It is, of course, desirable to collect more of such data.

We have not yet been able to obtain what we feel we can accept as standing-crop measurements which would enable us to draw a reliable inference as to the relationship between standing crop and productivity. From the pigment samples, Secchi disk readings, and the plankton volumes obtained at the same time as the productivity samples, it is clear, however, that there is an increase in standing crop as shore is approached.

From inspection of Figure 2 it appears not unlikely that an asymptotic value for carbon fixation would be obtained in the waters beyond Station 1 at least at some point along the next 100 miles off shore. Similarly it appears that some finite value could be reached in the waters nearest the shore and that perhaps this finite value would be within the next order of magnitude above that of the fixation obtained at Station 4 in Kaneohe Bay. If this highest inshore value can be added to that representing the productivity of the inshore benthic algae one may have a value which, when related to the energy falling per unit area, will be near a maximum for efficiency in our marine conditions under climax circumstances.

Acknowledgement

This work was supported by the research grant AT(04–3)15 of the U.S. Atomic Energy Commission and by Pacific Island Research Funds of the University of Hawaii. The technical assistance of Messrs. Clarence SUZUKI, Everet C. JONES, Leonard WOLFE, and Dr. Robert GUILLARD is gratefully acknowledged.

Summary

To test the hypothesis that as oceanic island shores are approached there is an increase in phytoplankton productivity, and to determine its magnitude, an experimental collection of data was obtained by means of the light and dark bottle technique and carbon fourteen. Over the 14-month period of sampling a consistent increase of nearly two orders of magnitude was observed in carbon fixed per hour per cubic metre of surface water, as Oahu (in the Hawaiian Islands) was approached from a position averaging 15 miles off shore to windward. The particular experimental conditions yield calculated raw data figures increasing regularly from 0·096 milligrammes of carbon photosynthetically fixed per hour per cubic metre at the furthest off shore station to 4·2 in Kaneohe Bay.

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A Method for the Microscopic Examination and Manipulation of Plankton on Board Ship

By

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Introduction

In certain regions of the Pacific there are sharp boundaries to the plankton faunas. The causes of these boundaries, indicated by the abrupt disappearance of certain species and the equally abrupt appearance of other species, are still not known. In order to study these boundary regions and the environmental factors associated with them in more detail, it is desirable to have some way of examining the zooplankton while at sea. RUSSELL (1935: 517), who apparently was the first to have attempted synoptic plankton studies at sea, did not use a microscope as the changes he was studying could be seen with the unaided eye. In the inshore region this is frequently the case, but in the oceanic realm faunal boundaries, although quite sharp, are not readily distinguished without the use of a microscope. Although some microscopic examination of plankton has been done at sea, there appear to be few published descriptions of the methods used.

The following paragraphs describe a device, the under-way plankton tray, made for the examination of plankton on board ship. With this apparatus it has been possible while at sea to examine and manipulate with probes and pipettes, at magnifications up to 100 ×, not only living and preserved zooplankton, but also the larger phytoplankton. Besides being useful for determining the kind and number of organisms present in the water, the tray should prove useful in other types of studies. Objects such

[1]) Contrib. Scripps Inst. Oceanogr., N.S., 873.
[2]) Contrib. Lamont Geol. Observ., 185, Biol. Progr., 9.

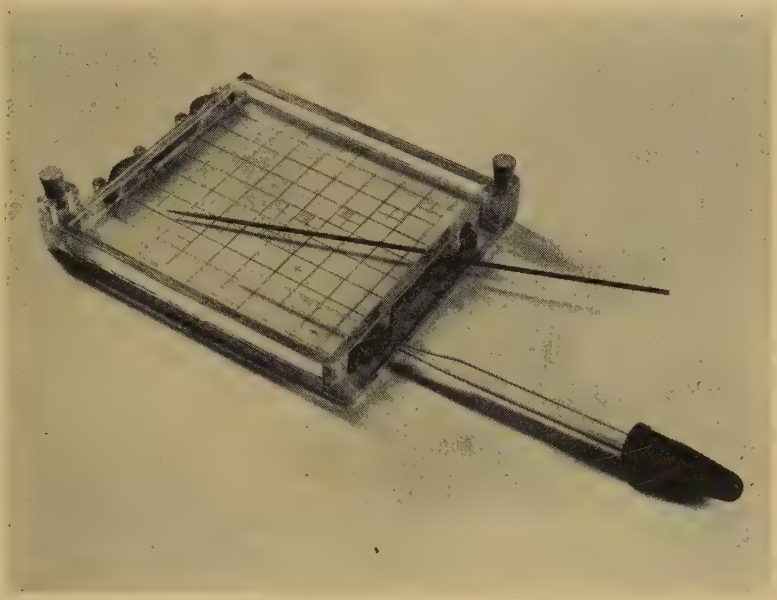

Figure 1. Under-way plankton tray with lid in place and a probe and pipette inserted through two of the entrance ports.

as large diatoms, small copepods, and fish eggs can be removed from plankton samples while alive and isolated for further study. Dissections of living organisms could probably be performed for physiological, embryological, or anatomical studies.

Description and Methods

The device is essentially an acrylic plastic tray and lid. At two opposite corners are air vents, and along two sides are entrance ports. A tray that has been in use for several months is shown in Figure 1. The dimensions are given in Figure 2. The lid, not shown in Figure 2, is a piece of $\frac{1}{8}$-inch plastic $4\frac{3}{16}$-inches (10·7 cm.) square with a $\frac{1}{8}$ by $\frac{1}{16}$-inch groove cut around its edges.

In operation the entrance ports on each side are covered by a taut rubber band. After the edges of the cover have been coated with stopcock grease, the tray is set on a table hung on shockmounted gimbals. Sixty millilitres of the sample to be examined are poured into the tray and the cover is put firmly in place. The table is then balanced so that the air bubble under the cover moves to one of the air vents. The other air vent is stoppered and the tray completely filled by means of a pipette. When the remaining air vent is stoppered, the tray can be lifted from the table to the stage of a microscope which has been firmly clamped to a suitable bench. The microscope and tray then roll and pitch with the ship.

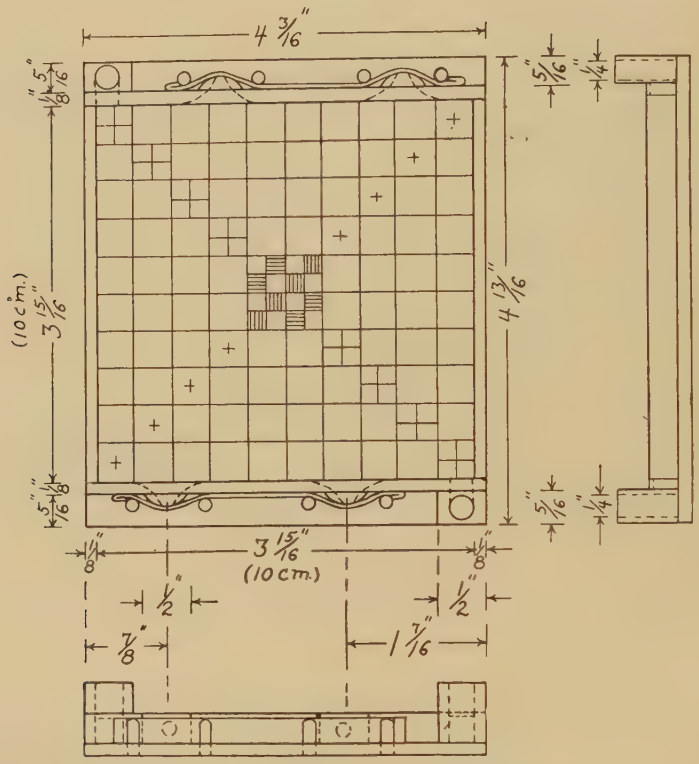

Figure 2. Dimensions of the under-way plankton tray. Lid not shown.

Probes about 6 inches long, made of $\frac{1}{16}$-inch diameter stainless-steel welding rod can be easily inserted through the side ports if they are lightly coated with stopcock grease. Glass pipettes (about 2 millimetres outside diameter) can also be readily inserted through the ports and used to remove small organisms. In Figure 3 the tray, microscope, and table set on gimbals are shown as used on board the research vessel "Vema". The device has been used successfully on the R/V "Baird" in moderate seas (28° maximum roll) and on board the R/V "Vema" in light seas (15° maximum roll). Although one can feel considerable vibration on both these ships, vibration of the microscope was not objectionable except occasionally at 100 × magnification.

Acknowledgements

The prototype of the under-way plankton tray described here was made and tested while the author was at the Scripps Institution of Oceanography. The instrument was improved and brought to its present stage of development at the Lamont Geological Observatory with the aid of funds from a grant of the Rockefeller Foundation for research in deep-sea biology (RF54087).

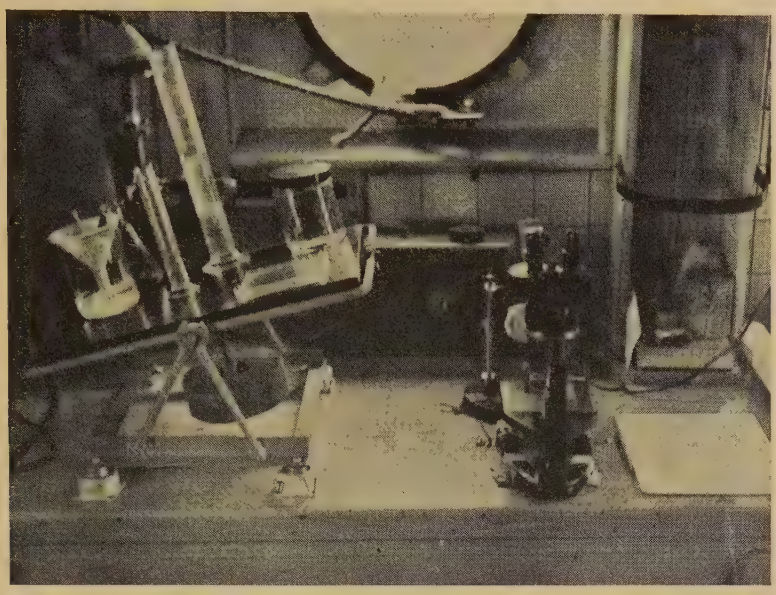

Figure 3. Under-way plankton tray on gimbal table filled and ready to be transferred to the microscope stage.

Reference

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On Day and Night Variation in Catches of Fish Larvae

By

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Introduction

Many of the problems connected with the herring stocks of the North Sea call for a knowledge of the area and extent of the spawning grounds, the relative importance of the spawning seasons from year to year, and the subsequent fate of the larvae deriving from them. The present paper describes tests made with new and with already published data in order to find a suitable net for assessing the number of larvae present. The results are mainly of a negative nature, since all the nets tested were found to be subject to an error which makes them unsuited to this work. A high-speed tow-net of wide gape is now being tested.

The Helgoland Larva Net

The net referred to in this paper was described and first used by KÜNNE (1933). It has since been used by a number of workers, notably BÜCKMANN, to study the distribution of herring larvae in the North Sea. The net is of 60-mesh silk, and is usually hauled at 50 cm./sec. by the BUCHANAN-WOLLASTON (1914) counterweight method. It samples a water column of $1\frac{1}{3}$ m^2. cross-section from within 4 m. of the sea bed.

The material used for the test consists of all the young pilchards taken on three pilchard-egg cruises in the English Channel by the research vessel "Sir Lancelot" during the summer of 1950, and all the young herring taken on 5 cruises by the "Sir Lancelot" and "Platessa" in the Southern Bight and Straits of Dover during 1952 and 1953. The catch from each haul was preserved separately in 2% formalin in sea water. These catches were placed in a Petri dish supported above an inclined white board illuminated by a distant lamp, and the larvae were separated from the rest of the plankton.

Table 1

Stage	Degree of development	Length range mm.
I	Yolk-sac over half full and no rays in fin fold in caudal region	6– 9
II	Yolk-sac vestigial or completely resorbed, fin rays in caudal region only	8–12
III	Fin rays in dorsal as well as caudal region	11–18
IV	Fin rays developed in anal region	16–25
V	Fin rays in pelvic, dorsal, anal, and caudal regions. This group covered all remaining larvae, none of which showed signs of scales	23–35

In order to describe their degree of development a system of staging based on a morphological character, the presence of fin rays, was devised. The criteria used and the length-range obtained by measuring 100 herring larvae of each stage are given in Table 1. Staging was carried out against a black background, with top lighting and with a microscope of 7–30 magnification.

Separation of the larvae into herrings, pilchards, and sprats was then carried out according to LEBOUR's (1920) criteria of myotome counts. A sample of at least 10% of each stage caught at each station was identified. The numbers of pilchard and sprat larvae found among the herring were negligible. Some anchovy larvae were found among the pilchards. The numbers of herring and pilchard larvae examined are given in Table 2, together with the number of hauls.

A comparison of repeated hauls

Attempts have already been carried out to estimate the error of one observation with the Helgoland larva net when used to sample small plankton animals, mainly copepods. WINSOR and WALFORD (1936), using KÜNNE's (1933) data, found a coefficient of variation of $\pm 25\%$. WINSOR and CLARKE (1940), using part of KÜNNE's data, found it to be $\pm 47\%$ with copepods, small medusae, *Tomopteris*, and *Sagitta*. In order to get an estimate of the variance of a catch of fish larvae, 10 hauls were made at a station where pilchard larvae occurred and 9 further hauls were made at a station where herring larvae were abundant. Variances were computed from numbers transformed by log. $(n + 1)$. Both tests were carried out at night with no wind and a calm sea, and the nets came up vertically. The variation in both series (1·51 and 0·63 times the mean for pilchards and 1·42 and 0·70 times the mean for herring) suggests that at night catches of fish larvae are as variable as those of other plankton animals.

Table 2

Numbers of larvae examined at each stage

Stage	I	II	III	IV	V	Total	Number of hauls
				Herring			
	23	10,025	1,506	426	47	12,027	625
				Pilchard			
	95	2,752	864	111	–	3,822	204

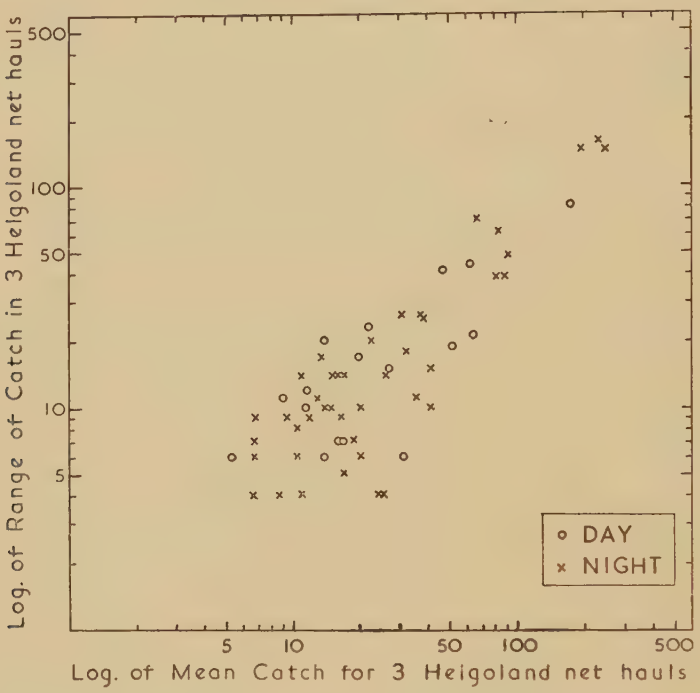

Figure 1. A comparison of the variation in the catch of herring larvae within a series of three hauls made with the Helgoland larva net.

Comparable tests were not made in daylight but it has been possible to compare the variation within 3 hauls both by day and by night from the material obtained on the herring larvae cruises. For the purposes of this comparison all stations having a mean catch of more than 5 larvae per haul have been used. The log. range (highest catch minus lowest catch) plotted against the log. mean catch for each series of 3 hauls is shown in Figure 1. The observations made by day do not appear to be subject to greater variation than those made at night.

Large catches of larvae, however, were seldom made in daylight, and when the effect of day and night on the catches of the Helgoland net was studied, an error far greater than the variation between successive hauls came to light.

Day and Night Variation in the Catches of Herring, Pilchard, and Plaice Larvae

While the clupeid larvae were being separated from the total plankton catch, it was noticed that the more productive hauls were those made at night. This is in accordance with the findings of other workers who used other nets. JOHANSEN (1925), using a 2-m. ring-trawl to sample herring

Table 3

Numbers of herring larvae of each stage caught by day and by night

	I	II	III	IV	V	Total[1])	Number of hauls
Day	19	1,005	129	8	–	1,266	235
Night	4	9,020	1,377	418	47	12,761	390

[1]) Includes some unstaged larvae.

larvae, found that catches were larger by night than by day. RUSSELL (1926), using a similar net, found an increase in the catches of pilchard larvae at all depths during the hours of darkness. WALLACE (1924), using PETERSEN's young-fish trawl, noticed considerable variation in the catches of young herring and sand eels in a series of hauls over 24 hours at the same station, but did not connect the variation with the time at which the hauls were made. More recently SILLIMAN (1943) noticed that the catches of Californian pilchard larvae made with a 1-m. silk tow-net increased at night. SOLEIM (1942) showed that the catches of herring larvae with both vertical and horizontal nets were higher on overcast days than on clear, sunny days. I was unable, however, to find a reference to the extent of this increase in catch at night. It was decided therefore to try to obtain from the data available an estimate of the variation to be expected, so that hauls made in daylight might be compared with those made at night.

Herring larvae

The herring larvae cruises of the "Sir Lancelot" and "Platessa" were carried out in January and February 1952 and January 1953, and for the purpose of this comparison day during these cruises was taken as from 0800 to 1600 hrs. and night from 1600 to 0800 hrs. G.M.T.

When the results were grouped in this way it was found that 90% of the total catch had been taken by night. The number of larvae of each developmental stage taken by day and night, together with the number of hauls, is given in Table 3. When the number of hauls was taken into account, the ratio of the mean catch by night to the mean catch by day, irrespective of the degree of development, was found to be nearly 7:1. This ratio of night to day catches is hereafter called the night/day ratio. Further, it may be seen from Figure 2 that the night/day ratio increases as the larvae become more developed. Stage IV larvae were rarely taken in daylight, and in 235 daylight hauls not one Stage V larva was caught.

Table 4 shows that on each of the five cruises the catch of stages II–V at night was greater than the catch by day. There is considerable variation between cruises, especially in the night/day ratios for a particular stage of development. This is to be expected, since some of these ratios are based on catches of comparatively few larvae. To show that the ratios obtained were not the result of a few large hauls at night, the catch at each station was plotted against the time of day at which the hauls were made. Figure 3 shows histograms of the catch on each of the five days of the "Sir Lancelot's" Cruise 2, 1952. It will be seen that on five consecutive days the catch

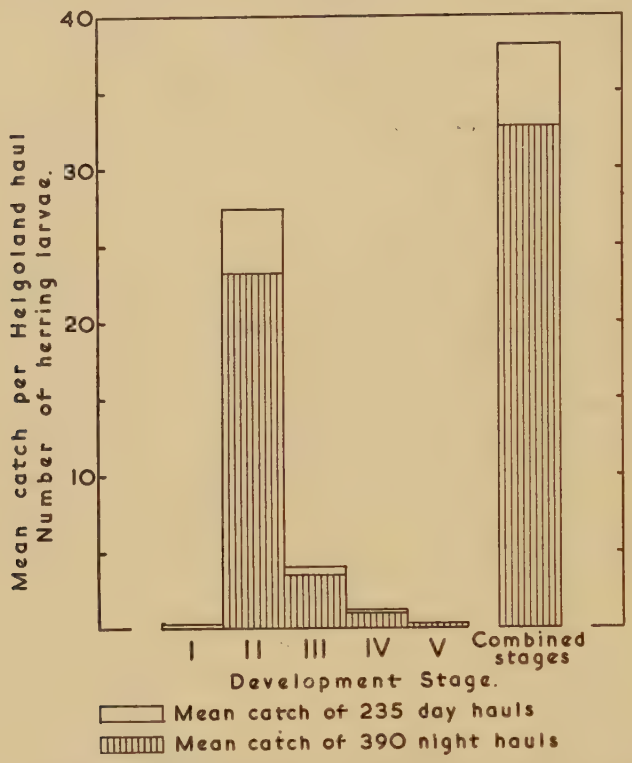

Figure 2. A comparison of the mean day and night catches of herring larvae of each development stage taken with the Helgoland larva net.

increased at night, and that during daylight hours it seldom exceeded 10 larvae. When the catches made on this cruise were transferred to a chart, the effect of the lower daylight catches was clearly seen. The area of greatest larval abundance had been crossed by eight lines of stations. Two of these lines were completed in daylight, the others being worked at night. The low values obtained on the daylight lines divided the area into three parts when contoured at over 25 larvae per station.

While it would be possible to obtain accurate estimates of the catch at night for each stage of herring larvae and to apply factors to daylight catches, it is doubtful whether abundance would be properly estimated over an area since catches of the later stages in daylight would require a factor of over 30. To apply such a factor to the very small numbers caught in daylight might well lead to as great an error as before.

Pilchard larvae

The pilchard larvae taken in the course of three cruises in the English Channel were separated from the total plankton catch and staged according to the criteria given in Table 1. Pilchard larvae, however, are smaller than

Table 4

Range of night/day ratios for each stage over 5 cruises

Larval stage	Helgoland Larva Net: Mean catch of night hauls	Mean catch of day hauls	Night/Day ratio	Cruise[1])
II.....	84·949	16·315	5·207	SL 1/52
	2·360	1·036	2.278	SL 2/52
	0·060	0·047	1·277	SL 3/52
	38·200	3·000	12·733	P 2/53
	5·625	2·286	2·461	P 2/52
III.....	3·010	1·500	2·007	SL 1/52
	3·897	0·337	11·564	SL 2/52
	2·716	0·118	23·017	SL 3/52
	7·400	0·000	∞	P 2/53
	9·250	1·429	6·473	P 2/52
IV.....	1·576	0·093	16·946	SL 1/52
	1·022	0·000	∞	SL 2/52
	0·910	0·035	26·000	SL 3/52
	0·000	0·000	–	P 2/53
	0·062	0·000	∞	P 2/52
V.....	0·000	0·000	–	SL 1/52
	0·059	0·000	∞	SL 2/52
	0·291	0·000	∞	SL 3/52
	0·000	0·000	–	P 2/53
	0·000	0·000	–	P 2/52
Total larvae.....	102·677	19·426	5·286	SL 1/52
	8·441	1·554	5·432	SL 2/52
	7·321	0·518	14·133	SL 3/52
	45·600	3·000	15·200	P 2/53
	14·937	3·714	4·022	P 2/52

[1]) SL = "Sir Lancelot"
P = "Platessa"

herring larvae of the same degree of development. The data were then treated in the same manner as those for the herring larvae catches, and night/day ratios obtained for each stage. Night, for the purposes of this comparison, was taken as the period from sunset to sunrise at Bristol on the first day of each cruise. The night/day ratios for each stage are shown in Table 5. The cruise ratios given in Table 6 are rather more consistent than those obtained from the herring data.

Plaice larvae

This experiment was carried out on the Brown Ridges in February 1953. Seven series of 3 hauls each were made with the Helgoland larva net between 1400 and 0940 hrs. the next morning. As the sea was calm and the wind light, the ship was allowed to drift throughout the experiment. The net came up vertically each time it was hauled. The catches of plaice eggs and larvae, expressed per 20 fathoms hauled, are shown in Figure 4. The use of the catch of eggs as a control suggests that the same population was sampled throughout the experiment. It is interesting to note that not only is the lowest night catch of larvae greater than the highest day catch but

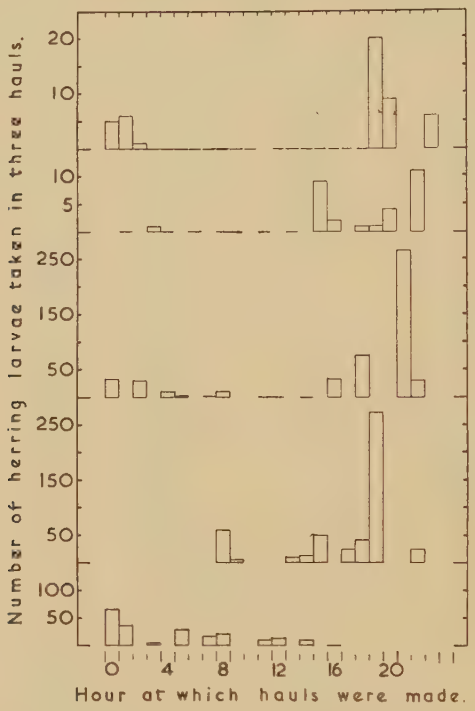

Figure 3. The catches of herring larvae taken at each station with the Helgoland larva net on five consecutive days.

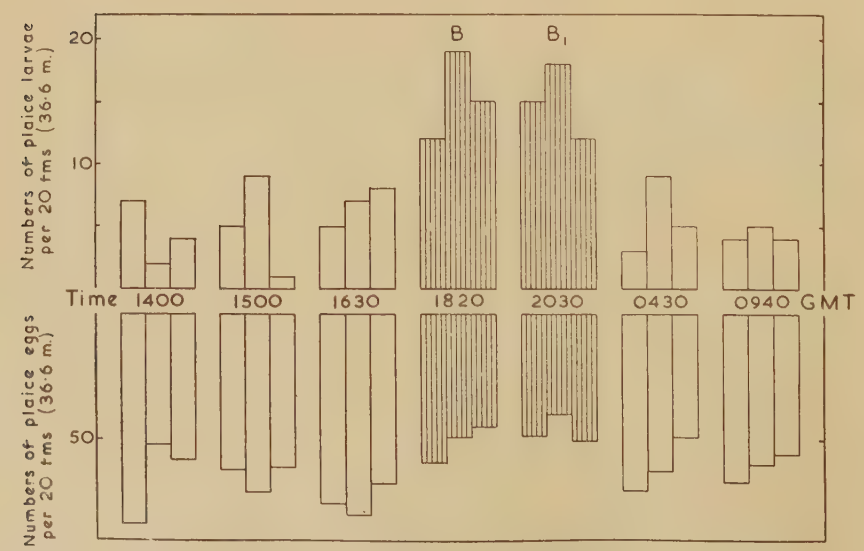

Figure 4. Catches of plaice larvae and eggs at the Brown Ridges on 12.–13. February 1953 made with the Helgoland larva net.

Table 5

Ratio of mean catch by night to mean catch by day for pilchard larvae

Development stages	I	II	III	IV	V	Combined stages
Mean catch, night ..	0·840	25·013	8·773	1·307	–	35·933
Mean catch, day....	0·248	6·791	1·597	0·101	–	8·737
Night/Day ratio	3·387	3·683	5·493	12·941	–	4·113

the two most productive hauls, marked B and B^1, were made with the ship's lights out.

While not conclusive in themselves, these results justify more extensive tests of the Helgoland net for catching fish larvae, which should be made before it is used for quantitative work, and these should include a test for the effect of the ship's lights on catches made at night.

A Comparison of the Catches of Young Clupeids made with the Helgoland Larva Net and the Hensen Egg-Net at the same Station

Hauls were made for pilchard larvae at night and for herring larvae both by day and by night. The work was carried out under ideal conditions and the nets, hauled by counterweight, came up vertically from within 4 m. of the bottom.

The pilchard larvae experiment was carried out on the "Sir Lancelot's" Cruise 14, 1950. The two nets were changed over on alternate hauls. The series, involving 10 hauls with each net, was completed within 2 hours. The catches are given in Table 7A, from which it can be seen that at night

Table 6

The variation in the night/day ratios for pilchard larvae obtained on 3 cruises

Mean catch, night	Mean catch, day	Night/Day ratio	"Sir Langelot" cruise No.	Development stage
1·34	0·47	2·8	7	I
0·81	0·30	2·7	10	
0·10	0·0	based on 2 larvae	12	
3·76	1·13	3·3	7	II
51·22	11·91	4·3	10	
20·21	6·20	3·3	12	
2·41	0·42	5·7	7	III
17·22	3·30	5·2	10	
6·47	0·80	8·1	12	
0·76	0·00	∞	7	IV
1·89	0·25	7·4	10	
1·32	0·02	57·2	12	
8·28	2·03	4·1	7	Total larvae
71·15	15·77	4·5	10	
28·10	7·02	4·0	12	

Table 7

Comparison of catches with the Helgoland larva net and Hensen net at the same station

A) Of pilchard larvae at night, 2200–0015 hrs. 13.–14. July 1950

Helgoland Net Development stages				Hensen Net Development stages			
II	III	IV	Total	II	III	IV	Total
19	3	–	22	1	1	–	2
4	4	–	8	1	1	–	2
7	2	1	10	5	1	–	6
17	2	1	20	–	–	1	1
5	1	–	6	–	–	–	–
15	2	1	18	–	1	–	1
18	–	–	18	5	–	–	5
7	4	–	11	9	1	–	10
20	1	1	22	3	–	–	3
14	–	–	14	5	1	–	6
126	19	4	149	29	6	1	36

Ratio of total 10 Helgoland larva net hauls to 10 Hensen net hauls	Stages II	III	IV	Total
	4·3	3·2	4·0	4·1

B) Of herring larvae stages II/III (11–13 mm.) at night, 1800–1930 hrs. 5. January 1953

Series	Helgoland Net Hauls A	B	C	Total	Hensen Net Hauls A	B	C	Total	Ratio Helgo.: Hensen
1	269	127	288	684	40	46	52	138	5·0:1
2	169	273	129	571	25	35	39	99	5·8:1
	Total of 6 Helgoland			1255	Total of 6 Hensen			237	5·3:1

C) Of herring larvae stages II/III (11–13 mm.) in daylight, 3.–6. January 1953

Series	Helgoland Net Hauls A	B	C	Total	Hensen Net Hauls A	B	C	Total	Ratio Helgo.: Hensen
1	28	21	11	60	–	7	1	8	7·5:1
2	8	16	5	29	–	1	2	3	9·7:1
3	78	64	61	203	5	14	5	24	8·5:1
4	38	72	31	141	6	9	5	20	7·0:1
	Total of 12 Helgoland			433	Total of 12 Hensen			55	7·9:1

the nets catch pilchard larvae in proportion to the areas of their mouths for all developmental stages.

The herring larvae experiments were carried out on the "Platessa's" Cruise 1, 1953, and on this occasion three hauls were made with each net in quick succession. The two night series were carried out at the same station on one night and the four day series were done in the same area during the next three days. The catches for the night series are given in Table 7B and the day catches in Table 7C.

It can be seen that the ratio of the catches of the two nets, Helgoland and Hensen, was not in proportion to the areas of their mouths, the smaller

Hensen net taking one-fifth of the catch of the larger net at night and one-eighth by day. It is possible that a proportion of the herring larvae even avoided the Hensen net at night, and there is no doubt that they did so by day.

This experiment reveals the danger of assuming that two nets fish in proportion to the area of their mouth openings. The nets used were exactly comparable in construction, differing in size only, and were hauled at the same speed, yet (by day) the larger net was almost twice as efficient. This result may be explained by comparing the radii of the two nets. The Helgoland larva net has twice the radius of the Hensen net, and so, in order to avoid capture, a larva directly in the path of the former net has twice as far to swim.

Day and Night Variation in the Catches of Clupeid Larvae by Other Nets

(a) The 2-metre stramin ring-trawl

The work of Russell (1926 and 1928) on the vertical distribution of young fish provides very useful information on the catches of larvae with the 2-m. stramin ring-trawl. In part III of his paper Russell gives the catches of pilchard larvae at various depths, down to within 10–15 m. of the bottom. These were obtained by carrying out a series of horizontal hauls occupying 48–72 hours at the same station. He notes that a marked increase in the catches occurred at all depths during darkness.

Table 8

Analysis of catches of pilchard larvae with a 2-m. ring-trawl

Source Russell	Time of day	Date	Number of hauls	Total catch (all depths)	Mean catch per haul	Larval size mm.	N/D ratio
Table 7.....	Day	15.7.24	5	192	31·0	–	
	Day	16.	5	118			
	Dusk	15.	5	107			7·2:1
	Dark	15.	5	1022	222·5	–	
	Dawn	16.	5	2208			
Table 8.....	Day	17.7.26	6	22			
		18.	6	15	2·9	–	
		19.	6	15			
	Dusk	17.	6	35	5·7	–	
		18.	6	34			
	Dark	17.	6	256	34·7	–	5·7:1
		18.	6	161			
	Dawn	17.	6	62	9·2	–	
		18.	6	48			
Table 9.....	Day	15.–16.7.24	10	264	26·4	5–10	6·0:1
	Dark	15.–16.	15	2377	158·5	5–10	
	Day	15.–16.	10	46	4·6	11–20	13·9:1
	Dark	15.–16.	15	960	64·0	11–20	
Table 10....	Day	17.–19.6.25	42	231	5·5	–	6·3:1
	Dark	17.–19.	12	417	34·7	–	

From the data in RUSSELL's tables, with the day and night catches separated (Table 8), the night/day ratio for each station was obtained. It can be seen that on three separate occasions the mean night catch was 5–7 times that of the mean day catch. On one occasion the mean catch per haul increased steadily from 2·9 larvae in full daylight to 5·7 at dusk and 34·7 at night, and then fell to 9·2 at dawn the next morning. For the series on 15.–16. July 1924, the only one for which the lengths of the larvae are given, the mean catch of larvae under 10 mm. increased sixfold at night while the catch of 11–20 mm. larvae increased 13·9 times.

It appears that the factors causing day and night variation in the catches of the Helgoland larva net also affect the catches of the larger, horizontally hauled ring-trawl. In fact the night/day ratio for the ring-trawl is greater than that for the Helgoland net. This is probably due to a difference in the degree of development of the larvae in the two sets of data. Pilchard larvae in stages III and IV gave ratios of 5·4 and 12·9 respectively when sampled with the Helgoland net, and if larvae of these stages were more abundant in RUSSELL's material than in ours, it would be possible to explain the difference between the night/day ratios of the two nets. On the other hand, the greater night/day ratio observed in the ring-trawl catches may mean that it is an even less efficient sampling device for pilchard larvae in daylight than the Helgoland net.

(b) **The Petersen young-fish trawl**

WALLACE (1924) used this net from the "George Bligh" on a long series of cruises in 1921–3 to study the distribution of herring larvae in the North Sea. The catches recorded in Table 1 of his paper are too extensive to repeat here and are referred to by their serial numbers only.

Treatment of WALLACE's data gives information on the following points:—

(a) the night/day ratio for the total catch of larvae;
(b) the night/day ratio for larvae of given length-groups;
(c) the daylight distribution of herring larvae in the water column, including the layers close to the bottom unsampled by the Helgoland larva net and the ring-trawl.

At many stations the net was used at surface, midwater, and bottom, and all such stations for which the times of the hauls were available in the log-books are considered in this section. These hauls number 248, out of 315, and they caught 54,450 out of the 58,789 larvae recorded in WALLACE's Table I. Night has been taken as sunset to sunrise on the first day of each cruise.

An analysis of WALLACE's data is given in Table 9. From this the following night/day ratios were obtained:—

Larvae under 9 mm.	2·0:1
– 10–19 mm.	3·9:1
– over 20 mm.	4·7:1
Total Catch	3·2:1

Table 9

Analysis of Wallace's (1924) young-fish trawl data
The number and size of herring larvae taken by day and by night

	Length mm. Under 9	10–19	Over 20	Total
Number of larvae caught in 118 night hauls	10,978	24,791	4,621	40,390
Mean catch per haul	93·03	210·09	39·16	342·29
Number of larvae caught in 130 day hauls.....	5,997	6,975	1,088	14,060
Mean catch per haul	46·13	53·65	8·37	108·15
Night/Day ratio	2·0	3·9	4·7	3·2

As in the case of the other nets, the increase in catch at night is related to the size and hence degree of development of the larvae being sampled. The vertical distribution of herring larvae in daylight obtained from Wallace's data gives no indication of a zone of high larval abundance close to the bottom. The mean catch by day at the surface and in midwater combined was 112 larvae per haul, while for the bottom hauls the mean catch was 103.

The occurrence of yolk-sac larvae is of interest because of their absence from our Helgoland larva net data. At ten stations over 3,000 young larvae were taken in all three hauls at surface, midwater, and near the bottom, and not predominantly in the bottom haul. It seems therefore that on or near a spawning ground, yolk-sac herring larvae should be available for capture by the Helgoland larva net in large numbers, and that their absence from our data is due to the fact that none of the stations occurred in such an area during the few days when yolk-sac larvae were abundant.

Further evidence of the increase in number and size of larvae caught at night has been furnished by the kindness of Professor A. C. Hardy, of Oxford University, who took part in the cruises referred to in this section. A 24-hour station was worked on the Schouwen Bank on 27.–28. March 1922 (Wallace, Table I, 54–57). Four series of three hauls (surface, midwater, and bottom) were made at 6-hour intervals, the ship drifting with the tide between stations. Post-larval herring and sand eels were taken. The length distribution of the herring larvae given in Wallace's Table 2 shows very clearly the greater size of the larvae taken at night compared with the day catches. The catches, with the times of each haul (not previously published), are given in Table 10 below. Unfortunately length distributions of the sand eels caught are not available, but a photograph of these catches in specimen jars kindly lent by Prof. Hardy clearly shows well developed

Table 10

Catch of herring and sand eels at a 24-hour station

Ref. No.	Time G.M.T.	Total Herring	Herring under 25 mm.	Herring over 25 mm.	Total Sand Eels
54	1900–2100	2,448	1,220	1,228	4,090
55	0615–0725	24	16	8	2,810
56	1410–1505	7	6	1	607
57	1905–2005	341	159	182	8,590

sand eels in both the night series, whereas they are absent from the two day series.

Another example of this increase in both number and size at night which can be found in WALLACE's data was quoted by GARDINER and GRAHAM (1925), but no times were given. Three series (WALLACE, 97, 98, 99) were carried out at the "Haisboro'" lightvessel between 1610 and 2035 hrs. on 9. November 1922. Series 97 at 1610 hrs. produced 759 larvae between 6 and 17 mm. in length; Series 98, 2,118 between 6 and 22 mm.; and series 99, at 2035 hrs., 2,530 between 6 and 25 mm.

Even with such a comparatively large net as the Petersen young-fish trawl, which can be fished at all depths, one cannot safely compare catches made by day with those made at night and any conclusions drawn from its catches must be reviewed in this light.

(c) The 1-metre silk tow-net

SILLIMAN (1943) has shown that Californian pilchard larvae of over 8 mm. in length can avoid this net when towed at 50 cm. per second in daylight. He states that "our regular surveys of the spawning grounds show the night catches of larvae to be consistently larger than by day" .This is in complete agreement with my herring and pilchard surveys with the Helgoland larva net, and my examination of WALLACE's young-fish trawl data. SILLIMAN does not give a numerical value for this increased catch, but it is easily calculated from his data. Taking the figures for actual catches at stations 2452 and 2454 from his Figure 37, we obtain the following values:—

	Night	Day	Night/Day Ratio
Total Catch of Larvae...	129	30	4·3:1
Larvae under 8 mm.....	25	15	1·7:1
Larvae over 8 mm.....	104	15	6·9:1

This is in very close agreement with the increase in our catches of pilchard larvae with the Helgoland larva net. The night/day ratio for all development stages combined is 4·1:1. While admitting that the numbers on which Californian night/day ratios are based are very small, we see nevertheless that the fourfold increase in the catch of larvae at night may be entirely attributed to the successful avoidance of the net by the larvae in daylight. This net was approximately the same size as the Helgoland net, and was hauled at the same speed horizontally as the latter was hauled vertically.

Conclusions

It has been shown that over a series of five cruises in which the Helgoland larva net was used, the mean catch of herring larvae was nearly 7 times as large by night as by day. When this net was used to catch pilchard larvae the mean night catch based on three cruises was 4 times as great as by day. Calculations based on published data have shown that the 2-m. ring-trawl, the Petersen young-fish trawl, and the 1-m. silk tow-net all catch more clupeid larvae by night than by day. These nets, therefore, do not give a

quantitative estimate of larval abundance, nor even a reliable qualitative estimate, unless day and night variation is allowed for in plotting the data. Erroneous impressions of the extent and relative importance of two spawnings could result from one being sampled at night and the other by day.

The issue is further complicated by the fact that for any of these nets the increased catch at night depends on the degree of development of the larvae being sampled. Factors to compensate for this error could be obtained, but when the factor is large and the actual catch to be treated is small, their value is doubtful. To obtain a quantitative estimate of larval abundance, therefore, it is necessary to discover why the catches are lower by day than by night and then develop an appropriate technique, employing, perhaps, a new net.

On the evidence presented it seems almost certain that the lower catches by day are due to the ability of the larger larvae to avoid the nets in daylight. This would explain the increasing night/day ratios obtained as the larvae develop and become more agile. Alternative explanations might be that in daylight the larvae congregate close to the sea bed, or that the larvae form shoals in daylight and disperse at night. The first seems improbable, however, since the Petersen young-fish trawl data obtained by WALLACE show the same sort of error in spite of the fact that hauls were made on, or very close to, the bottom and the mean catch in that zone by day was slightly less than in midwater. The second, that the larvae shoal by day, is not supported by the Helgoland larva net data shown in Figure 1. The variance within three hauls is of the same order for the day stations as for the night. If shoaling took place, one would expect markedly large variance between daylight hauls.

Before the success of a herring or pilchard spawning can be estimated, and larval mortality measured, it is essential to test the nets used for day and night variation, preferably by a series of hauls at one station which covers 24 hours. In the tests, it is desirable that the nets used should (a) be hauled at a speed well above 50 cm. per second, the mean speed of most larva nets in the past; (b) have the minimum number of warps and bridles immediately in the path when towed; (c) filter a large enough column of water to give catches of sufficient size for statistical analysis; (d) be fished close enough to the bottom to sample the full depth of water.

High-speed tow-nets in general fulfil requirements (a) and (b) but in the main are so small in gape that several hours steaming is required to produce a fair catch. Only one net has come to the author's notice, the Gulf III designed by GEHRINGER (1952), which meets all four requirements. This consists of a conical Monel-metal net with a gape of 16 ins. in a strong metal torpedo-shaped case which is taken to the required depth by a depressor. The original model was made of Monel metal throughout, but two have been made at Lowestoft with sheet galvanized iron used instead of Monel metal in the casing, to reduce the cost; Monel metal was used for the net. This net was used by the author and others in 1953 and appeared very satisfactory. It was perfectly stable, appeared to filter the water effectively at speeds of 4–6 knots, and caught sand eels, herrings, shrimps, and a 25 cm. plaice as well as very good quantities of plankton. It proved robust enough to stand striking a sandy bottom. However, with the depressor hung 6 feet

below the net, so that it ceased to function as soon as it touched the bottom, the net was seldom subjected to such a test. It has yet to be tested for day and night variation on clupeid larvae, but used with a flow-meter and depth recorder it offers the most hopeful approach yet to a quantitive study of brood strength and larval mortality.

Summary

1. Comparison of repeated hauls with the Helgoland larva net shows that catches of clupeid larvae have a percentage variation of 40–60%.
2. A very much greater source of error is found when the mean day and night catches of the Helgoland larva net are compared. Over a series of cruises this net took by night six times as many herring larvae, and four times as many pilchard larvae, as it did by day. The increase in the catch at night is not the same for all stages of development, but depends upon the degree of development of the larvae being sampled.
3. A comparison of the catches of the Helgoland larva net and the Hensen net at the same station shows that the smaller Hensen net did not catch herring larvae in daylight in the same proportion to its mouth opening as the Helgoland net. This can only be due to more successful avoidance of the smaller net by herring larvae of 10–12 mm. in length.
4. Published data on the catches of clupeid larvae with other nets are examined and all are found to give larger catches by night than by day. Again, the increase in the catch at night depends on the size, and hence development, of the larvae sampled.
5. Avoidance of nets hauled slowly during daylight hours appears to be the cause of the low day catches, and a high-speed tow-net of wide gape is suggested as a possible remedy.

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Liste des Parasites Animaux du Hareng de l'Atlantique Nord et de la Baltique

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Les parasites externes et internes du hareng, *Clupea harengus* L. 1758, sont encore très peu connus. La liste que j'en ai dressée est certainement incomplète. Je la présente néanmoins, en espérant qu'elle attirera l'attention des ichthyologistes spécialisés dans l'étude du hareng et qu'ils m'aideront à la compléter.

Coccidies

Eimeria sardinae (P. Thélohan 1890)
= *Eimeria oxyspora* C. Dobell 1919
= *Eimeria snijdersi* C. Dobell 1919.

C'est un parasite répandu chez plusieurs espèces de Clupeidae, non seulement chez le hareng, mais chez *Clupea pilchardus* Walbaum (où il a été découvert, à Concarneau, Finistère) et *Clupea sprattus* L.; il ne semble pas avoir été signalé ailleurs que dans les eaux Britanniques et à Concarneau. Il se trouve dans les testicules.

Eimeria clupearum (P. Thélohan 1894)
= *Eimeria wenyoni* C. Dobell 1919.

Ce parasite, d'abord connu seulement du foie du hareng à La Palice (Charente inférieure) et de la sardine à Concarneau (Finistère), a été retrouvé dans les eaux Britanniques chez le hareng, le sprat, et le maquereau; il est aussi connu de l'anchois à Cancale et de la sardine de Marseille et Villefranche.

Ceratomyxa sphaerula P. Thélohan 1892.

Cette microsporidie a été trouvée une fois dans la vésicule biliaire d'un hareng, à Bergen (Norvège); c'est habituellement un parasite de sélaciens (*Mustelus*, *Galeus*); il a été observé à Roscoff et à Saint-Valéry-en-Caux.

Kudoa clupeidae (C. W. Hahn 1917) P. A. Meglitsch 1947
syn. *Chloromyxum clupeidae* C. W. Hahn 1917.

Cette microsporidie n'est connue que dans les muscles du hareng et quelques autres téléostéens (Clupeidae, Labridae, Sparidae) de la côte atlantique des États-Unis, principalement du Massachusetts.

Trématodes Monogénétiques

Mazocraes harengi (P. J. van Beneden & E. Hesse 1863).

Ce parasite, découvert chez le hareng à Brest, a été retrouvé à Annan (Écosse). Il a été signalé aussi chez une autre espèce de clupéide, *Clupea alosa* L., de la région de Plymouth. C'est un parasite des branchies.

Trématodes Digénétiques

Brachyphallus crenatus (Rudolphi 1802).

Ce distome n'est connu chez le hareng que sur la côte atlantique du Canada et des États-Unis (Maine, Massachusetts) où il a été signalé aussi chez quelques autres téléostéens (*Anguilla*, *Osmerus*); il est connu au Groënland (chez *Lumpenus*) et sur les côtes scandinaves, en particulier de la Baltique, chez les téléostéens les plus divers (*Salmo*, *Pleuronectes*, *Gasterosteus*, *Cottus*, *Ammodytes*, *Osmerus*). C'est un parasite du tube digestif.

Hemiurus Levinseni T. Odhner 1905.

Ce distome n'a été signalé chez le hareng que sur la côte est du Canada. C'est un parasite de l'estomac de nombreuses espèces de poissons, Gadidae principalement, de l'Atlantique nord — Norvège, Danemark, mer de Barents, Groënland, Canada, côte des États-Unis jusqu'au Maine; signalé aussi dans le Pacifique — Puget Sound, Sibérie orientale; probablement circumpolaire.

Hemiurus halecis (Gmelin 1790)
= *Hemiurus ocreatus* (Rudolphi 1802)
= *Hemiurus lühei* T. Odhner 1905.

Ce distome est très commun dans le tube digestif du hareng de la mer du Nord et de la Baltique, de la côte de Belgique et du nord de la France; il est plus rare chez *Clupea sprattus* L. Il a peut-être été signalé sous un autre nom chez le hareng de la côte atlantique des États-Unis.

Derogenes varicus (O. F. Müller 1784) Max Lühe 1901.

A été trouvé très communément chez le hareng dans la région de Plymouth et une fois dans des kystes réactionnels sur les viscères et dans les muscles d'un hareng du Nouveau-Brunswick (Canada). Il parasite de très nombreuses espèces de téléostéens dans toutes les mers d'Europe (y compris la Baltique et la Méditerranée) jusqu'au nord de l'Islande, sur toute la côte atlantique

de l'Amérique du Nord (de l'extrême nord à la Floride); signalé aussi dans le Pacifique (du Canada à la Sibérie orientale), aux îles Galapagos, et sur les côtes de Chine.

Lecithaster confusus T. ODHNER 1905.

Cet hémiuride n'a été signalé chez le hareng que dans la région de Woods Hole (Massachusetts) et sur les côtes scandinaves; il est connu chez quelques autres espèces de téléostéens des mêmes régions et aussi chez *Alosa finta* (G. CUVIER) de la Méditerranée.

Lecithaster gibbosus (RUDOLPHI 1802) MAX LÜHE 1901.

Cet hémiuride n'a été signalé chez le hareng que sur les côtes scandinaves (y compris la Baltique), les côtes d'Écosse, et peut-être la côte est du Canada, mais c'est une espèce assez répandue chez de nombreuses espèces de téléostéens des côtes Britanniques; on la connaît du Groënland. Son extension géographique ne paraît pas limitée à l'Atlantique nord; il a été signalé chez divers téléostéens de la baie Pierre-le-Grand (Sibérie orientale).

Opechona bacillaris (R. MOLIN 1859) A. LOOSS 1907
= *Pharyngora bacillaris* (R. MOLIN 1859) W. NICOLL 1910.

Ce Lepocreadiinae a été communément observé chez des harengs à Plymouth, mais à Plymouth comme en Baltique et en Méditerranée, l'hôte habituel est *Scomber scombrus* L.; il a aussi été signalé chez quelques autres téléostéens des côtes d'Europe. C'est un parasite du tube digestif.

"*Distomum vitellosum* EDWIN LINTON" *partim.*

Sous ce nom, LINTON a désigné des distomes qu'il trouva dans l'intestin de 33 espèces de téléostéens, dont le hareng, à Woods Hole (Massachusetts) et, chez d'autres espèces, à Beaufort (Caroline du Nord), et aux Bermudes. Malheureusement ce nom est collectif, réunissant plusieurs espèces appartenant à au moins trois genres; l'on ne peut savoir à laquelle de ces espèces appartenaient les individus trouvés à Woods Hole chez le hareng.

Cestodes adultes

Bothriocephalus scorpii O. F. MÜLLER 1776.

Un immature de cette espèce a été signalé chez un hareng à Woods Hole (Massachusetts). C'est une espèce commune dans le tube digestif de beaucoup d'espèces de téléostéens. Il a été identifié chez environ 50 espèces diverses de poissons de toutes les mers d'Europe (y compris la Baltique, la Méditerranée, et la mer Noire), de l'Océan Glacial arctique, des côtes atlantiques du Canada et des États-Unis, au moins jusqu'au Massachusetts.

Eubothrium crassum (M. E. BLOCH 1779) O. NYBELIN 1922
= *Bothriotaenia proboscidea* (BATSCH 1786) V. ARIOLA 1900.

Ce pseudophyllide, parasite à l'état adulte dans les caeca pyloriques de plusieurs espèces de téléostéens d'eau douce (*Salmo* en particulier), a plusieurs fois été trouvé à l'état de larve plérocercoïde dans l'estomac et

l'intestin du hareng du golfe de Finlande, où l'eau est presque douce. Il n'est pas certain que l'espèce ait été trouvée ailleurs qu'en Europe centrale et subboréale. L'attribution à *crassum* des plérocercoïdes du hareng de la Baltique a été mise en doute par MAX LÜHE (1910); il se pourrait qu'il s'agisse en réalité d'*Eubothrium fragile* (Rud. 1802), qui est parasite des caeca pyloriques de *Clupea finta* CUVIER de l'Atlantique du Nord.

Cestodes larvaires

Digramma alternans (RUDOLPHI 1810)
syn. *Ligula digramma* CREPLIN 1839.

Cette espèce a été signalée par LINSTOW (1889 et 1896) comme ayant été trouvée chez le hareng, sans indication de localité ni référence bibliographique. Sous sa forme larvaire, c'est un parasite de la cavité abdominale de beaucoup d'espèces de poissons d'eau douce, principalement des cyprinides. L'adulte se trouve chez des oiseaux ichthyophages (*Gavia*, *Colymbus*, etc.) surtout dans le nord de l'Europe (Allemagne du Nord, Russie).

Lacistorhynchus tenuis (P. J. VAN BENEDEN 1858)
= *Rhynchobothrium bulbifer* EDWIN LINTON 1890
= *Rhynchobothrium heterospine* EDWIN LINTON 1890.

La larve plérocercus de ce tétrarhynque a été signalée enkystée dans la musculature et sur les viscères, ou introduite avec la nourriture dans l'intestin, chez le hareng, à Woods Hole (Massachusetts). Cette larve est connue chez environ 70 espèces de poissons des mers d'Europe (y compris la Méditerranée) et de la côte atlantique des États-Unis (Massachusetts); elle a aussi été signalée dans le Pacifique (South California). L'adulte parasite divers sélaciens (*Galeus*, *Mustelus*, *Acanthias*, etc.).

Grillotia erinaceus (P. J. VAN BENEDEN 1858)
= *Rhynchobothrium imparispine* EDWIN LINTON 1890.

La larve plérocercus a été signalée enkystée dans la paroi de l'estomac, chez le hareng, à Woods Hole (Massachusetts). Cette larve plérocercus est connue chez plus de 30 espèces de téléostéens des côtes d'Europe (Atlantique, mer du Nord) et 37 espèces de téléostéens + 2 espèces de sélaciens de la côte atlantique des États-Unis (Massachusetts). L'adulte est connu chez environ 23 espèces de sélaciens (Atlantique, mer du Nord, Méditerranée; Maine et Massachusetts).

Scolex pleuronectis O. F. MÜLLER 1780.

Cette larve a été signalée dans le tube digestif du hareng à Varberg (Suède) et sur la côte du Boulonnais. Dans les hôtes les plus divers (poissons et invertébrés marins) du monde entier, on a signalé *Scolex pleuronectis* O.F.M. = *Scolex polymorphus* RUD.; il correspond à diverses espèces de cestodes tétraphylles.

Plusieurs fois des larves indéterminées de cestodes ont été signalées chez le hareng de la région de Plymouth et de l'Écosse.

Nématodes adultes

Contracaecum aduncum (RUDOLPHI 1802) H. B. WARD 1918
= *Ascaris clupeae* P. J. VAN BENEDEN 1870.

Chez le hareng, des larves âgées et des adultes ont été trouvés dans le tube digestif, sur les côtes de Belgique et du Boulonnais. Il n'est pas certain que *C. aduncum* (RUD.) soit la même espèce que *C. gadi* (O.F.M.) = *clavatum* (RUD.). L'hôte type d'*aduncum* est *Alosa alosa* (L.). Un certain nombre d'auteurs ont signalé ce nématode chez les poissons les plus divers des côtes d'Europe et de la côte atlantique des États-Unis; on a cru l'avoir retrouvé chez un poisson du sud de la Terre de Feu.

Dans l'intestin du hareng des côtes d'Islande a été signalé *Raphidascaris acus* (M. E. BLOCH 1779), mais c'est un nématode du brochet *Esox lucius* L. et de quelques poissons de mer vivant en eau presque douce dans la Baltique. Sa présence chez le hareng devra être confirmée.

Nématodes larvaires

Contracaecum aduncum (RUDOLPHI 1802).

Des larves âgées (et des adultes) ont été trouvées dans l'estomac et l'intestin de harengs du nord de la France et de la Belgique. Des larves encapsulées sur le foie ont été signalées chez des harengs de la Baltique polonaise.

Contracaecum spiculigerum (RUDOLPHI 1809) A. RAILLIET & A. HENRY 1912.

Des larves trouvées dans le péritoine de harengs de la côte atlantique des États-Unis ont été attribuées par A. C. WALTON (1928) à cette espèce qui, à l'état adulte, parasite le tube digestif de divers oiseaux ichthyophages (*Phalacrocorax*, *Pelecanus*, etc.) surtout de l'Atlantique nord.

Porrocaecum (*Terranova*) *decipiens* (H. KRABBE 1878).

Des larves trouvées libres dans l'intestin de harengs de la côte atlantique des États-Unis ont été attribuées à cette espèce par A. C. WALTON (1928), mais la larve de *decipiens* est surtout connue comme encapsulée dans la musculature de nombreuses espèces de poissons, en particulier de la morue. L'adulte parasite de nombreuses espèces de pinnipèdes et a même été récolté chez un cétacé (*Phocaena phocaena* (L.)) dans la Baltique. Les pinnipèdes hôtes définitifs habitent l'Atlantique nord et ses dépendances, le Pacifique nord, et même les mers subarctiques.

Anisakis sp.

Il est possible que des larves d'*Anisakis* parasitent le hareng; on trouve, dans le foie, l'estomac, l'intestin, la cavité générale des harengs d'Islande, du Canada, et d'Europe septentrionale, des larves qui sont encore trop jeunes pour que l'on puisse savoir avec certitude si elles appartiennent au genre *Anisakis* ou au genre *Porrocaecum*.

Capsularia halecis J. G. H. ZEDER 1800
= *Ascaris harengum* SCHRANK 1788.

Cette larve, enroulée en spirale régulière, plane, est communément trouvée

encapsulée dans la musculature et la cavité générale chez les harengs du nord de l'Europe (mer du Nord, Baltique); l'on a supposé qu'elle correspondait à *Anisakis simplex* (Rud.), adulte dans l'estomac de nombreuses espèces de cétacés de l'hémisphère nord et aussi signalé chez des cétacés de la Nouvelle Galles du Sud et de la Nouvelle Zélande.

Eustoma rotundata (Rudolphi 1819) A. Punt 1941
= *Anacanthocheilus rotundatus* (Rudolphi 1819) G. Wülker 1929.

La larve le plus souvent observée dans la musculature et la cavité générale, enroulée en spirale dans une gaine, chez le hareng de Norvège et de la mer du Nord, a été attribuée à cette espèce par G. Wülker et W. Kahl. Cette attribution a été contestée par Arie Punt (1942).

La même larve a été signalée encapsulée chez plus de 12 espèces de téléostéens. L'adulte parasite diverses espèces de sélaciens des mers d'Europe (de la côte mourmane à la Méditerranée) et de l'Atlantique nord-américain.

Acanthocéphales

Serrasentis socialis (J. Leidy 1851) H.'J. van Cleave 1923.

La postlarve, encapsulée dans l'abdomen d'un hareng, a été signalée sur la côte atlantique des États-Unis. Des larves enkystées ou des immatures ont été identifiés chez environ 13 espèces de poissons de la côte atlantique des États-Unis. L'adulte est connu dans l'intestin de *Pseudopleuronectes americanus* (Walbaum) de la côte atlantique des États-Unis. L'espèce a été aussi trouvée sur les côtes du Queensland et de la Nouvelle Galles du Sud.

Echinorhynchus gadi Zoëga *in* O. F. Müller 1776.

Cet acanthocéphale a été trouvé dans l'intestin du hareng seulement dans la Baltique (Kattegat, Suède, Pologne, Finlande). Il est commun chez la morue et parasite aussi d'autres espèces de poissons; il est commun dans la mer du Nord et sur les côtes de l'extrême nord de l'Europe (côte mourmane, mer Blanche); sur la côte atlantique de l'Amérique du Nord (Massachusetts) il a été signalé chez 54 espèces de poissons; on le connait aussi sur les côtes nord-ouest du Canada, à l'île Béring, au Kamtschatka, et jusqu'au Japon chez des téléostéens d'espèces très diverses.

Echinorhynchus salmonis O. F. Müller 1784.

Cette espèce n'a été trouvée chez le hareng que dans le golfe de Botnie et le golfe de Finlande; elle a été signalée chez environ 35 espèces de poissons, principalement d'eau douce, d'Europe, surtout du nord, non seulement en mer à peine salée, mais aussi dans des lacs de Suède et de Finlande. C'est un parasite de l'intestin pour le hareng.

Echinorhynchus clavula F. Dujardin 1845.

Cette espèce n'a été signalée qu'une seule fois chez le hareng — sur la côte de Finlande. Elle est surtout parasite de poissons d'eau douce ou de poissons de mer vivant en eau presque douce comme dans la Baltique; il n'est pas certain qu'elle existe dans le sud de l'Europe et hors d'Europe. C'est un parasite de l'intestin pour le hareng.

Pomphorhynchus laevis (ZOËGA *in* O. F. MÜLLER 1776).

Cet acanthocéphale n'a été signalé chez le hareng que deux fois et seulement sur la côte suédoise de la Baltique. L'espèce est représentée dans toute l'Europe (jusqu'à la mer Blanche au nord, jusqu'à la Caspienne et à la Méditerranée au sud), chez de nombreuses espèces de téléostéens, surtout d'eau douce. Il n'est pas certain que ce soit la même espèce qui ait été signalée sous le même nom aux États-Unis et au Canada. C'est un parasite de l'intestin pour le hareng.

Corynosoma strumosum (RUDOLPHI 1802) MAX LÜHE 1904.

Cet acanthocéphale, à l'état larvaire, a été identifié chez le hareng seulement dans la Baltique. Cette espèce est connue, larvaire aussi, chez d'autres téléostéens, les uns d'eau douce, les autres marins vivant comme en Baltique dans des eaux de faible salinité. L'hôte définitif est un pinnipède (*Halichoerus*, *Phoca*, *Cystophora*, *Erignathus*, *Otaria*), rarement un cétacé (*Phocaena*, *Delphinapterus*); il peut aussi être un oiseau (*Phalacrocorax*, *Sterna*). La distribution géographique comprend tout le nord de l'Europe, jusqu'à Arkangelsk, une partie de la Russie jusqu'à la Caspienne, le Groënland, la Colombie britannique; des oiseaux venant du nord peuvent le conserver jusque dans des régions tempérées et même tropicales.

C'est un parasite péritonéal pour le hareng.

Corynosoma semerme (A. L. FORSSELL 1904) MAX LÜHE 1911.

Cet acanthocéphale, à l'état larvaire, a été identifié chez le hareng seulement dans la Baltique. Il a aussi été identifié chez d'autres téléostéens de la Baltique, espèces d'eau douce et espèces marines vivant en eau presque douce. L'hôte définitif est un pinnipède (*Halichoerus*, *Phoca*, *Trichecus*, *Otaria*), rarement un cétacé (*Phocaena*); il peut être aussi un oiseau (*Phalacrocorax*, *Mergus*, *Podiceps*, *Uria*). C'est surtout une espèce du nord de l'Europe et probablement circumpolaire, étant connue du Groënland, du Canada, de l'île de Béring; cependant elle a été identifiée chez le phoque de la Caspienne et chez un oiseau migrateur à Antigua (Antilles anglaises).

C'est un parasite de la cavité générale pour le hareng.

Copépodes

Caligus rapax H. M. EDWARDS 1840.

J'ai trouvé un mâle dans la cavité buccale d'un hareng à Stornoway (Écosse). Cette espèce se trouve sur de nombreuses espèces d'autres téléostéens et sur des sélaciens dans tout l'Atlantique nord jusqu'en Islande et au Groënland; elle parait abondante sur la côte atlantique du Canada et des États-Unis au moins jusqu'aux Massachusetts; on l'a aussi trouvée sur la côte atlantique de France et en Méditerranée occidentale.

Lepeophtheirus pollachius P. W. BASSETT-SMITH 1896, forma *harengi nobis*.

J'ai trouvé, dans la cavité buccale d'un hareng, à Stornoway (Écosse) un specimen mâle que j'estime ne pas pouvoir être rapporté à l'espèce *pollachius* autrement qu'en le considérant comme une variété ou forme particulière,

bien distincte. *L. pollachius* BASSETT-SMITH semble n'avoir pas été signalé ailleurs que dans la cavité buccale de *Gadus pollachius* L. et *Molva molva* (L.), des îles Britanniques, de Roscoff, de Concarneau, et de l'île d'Yeu (Vendée).

Lernaeenicus sprattae (JAMES SOWERBY 1806).

Deux individus femelles furent trouvés fixés à la cornée d'un hareng de la côte du Devonshire. La femelle, fixée à l'oeil ou au dos de *Clupea sprattus* L., est commune sur les côtes d'Europe occidentale (France et îles Britanniques principalement); elle a aussi été signalée en Méditerranée.

Nous ignorons complètement si quelques uns de ces parasites affectent la vie du hareng. Peut-être la connaissance de la biologie de quelques uns d'entre eux aurait-elle une importance pratique.

Addendum

Une liste des parasites des harengs de la mer Blanche a été récemment publiée par S. S. SCHULMAN et R. E. SCHULMAN-ALBOVA (1953)[1]. Pour *Clupea harengus pallasi maris-albi* BERG, ces auteurs mentionnent 17 espèces — *Ceratomyxa orientalis* V. DOGIEL 1948, *Chloromyxum* sp., *Sphaerospora orientalis* S. S. SCHULMAN et R. E. SCHULMAN-ALBOVA 1953, *Eimeria sardinae* (P. THÉLOHAN 1890), *Brachyphallus crenatus* (RUDOLPHI 1802), *Lecithaster confusus* T. ODHNER 1905, *Derogenes varicus* (O. F. MÜLLER 1784), *Metacercaria*: *Diplostomum spathaceum* (RUDOLPHI 1819), *Eubothrium crassum* (M. E. BLOCH 1779), *Scolex polymorphus* RUDOLPHI 1819, *Pleudophyllidea* gen.?, sp.? (2 formes ou espèces), *Anisakis* sp., *Contracaecum aduncum* (RUDOLPHI 1802), *Terranova decipiens* (H. KRABBE 1878), *Corynosoma semerme* (A. L. FORSSELL 1904), *Corynosoma strumosum* (RUDOLPHI 1802), *Echinorhynchus gadi* ZOËGA *in* O. F. MÜLLER 1776.

Pour *Clupea harengus pallasi maris-albi* BERG forma *major*, 7 espèces sont citées — *Ceratomyxa orientalis* V. DOGIEL 1948, *Sphaerospora orientalis* S. S. SCHULMAN et R. E. SCHULMAN-ALBOVA 1953, *Brachyphallus crenatus* (RUDOLPHI 1802), *Scolex polymorphus* RUDOLPHI 1819, *Anisakis* sp., *Terranova decipiens* (H. KRABBE 1878), *Contracaecum aduncum* (RUDOLPHI 1802).

[1]) "Parasites des poissons de la mer Blanche". 200 pp., 23 figs. texte; Publication de l'Académie des Sciences de l'U.R.S.S., Filiale Carélo-Finnoise de l'Institut de Biologie. Moscou-Leningrade, 1953.

On the Interpretation of the Opaque and Hyaline Zones in the Otoliths of Immature Redfish (*Sebastes marinus* L.)

By

Erling Bratberg

Introduction

Until about 20 years ago the redfish (*Sebastes marinus* L.) played only a minor part in the fisheries of northern Europe, but since then the position has completely changed. One may say that today the redfish is among the most important of our commercial food fishes. Nevertheless the study of the biology of the redfish has been somewhat neglected, but the growing commercial importance of the species is attracting more of the interest of the fishery biologists. It must be admitted that our knowledge about the redfish is very deficient, and is largely based on a few scattered observations.

It is generally recognized that information on age, rate of growth, and maturity is needed in order that overfishing of a stock may be checked. In regard to the redfish several scientists have attempted to obtain this information, but the determination of age has proved rather difficult, and certain disagreements have arisen between various investigators. These do not seem to arise from the existence of different rates of growth in different areas, but spring rather from differences in the interpretation placed on the zones in the otoliths and in regard to the manner of their formation. Some scientists — for instance, SMARAGDOVA (1936), and Alfred PERLMUTTER and George M. CLARKE (1949) — state that the redfish grows very slowly, and does not become mature until it is at least 10 years old. Others — KOTTHAUS (1949, 1952), for example — are of the opinion that the redfish is a fast-growing fish which reaches maturity at 3–4 years of age.

During the years 1951–1953 the age and growth of immature redfish were investigated by the present author at the University Biological Laboratory in Oslo, in co-operation with the Institute of Marine Research, Directorate of Fisheries, in Bergen.

Material and Methods

Collection of material for the present investigation was started in July 1951 and concluded in December 1952. The working up of the material was completed by May 1953. The samples of redfish were obtained in three adjacent localities on the Norwegian coast in about latitude 64°N. An ordinary 36-foot shrimp-trawl was used, with a mesh-size in the cod-end of $1\frac{1}{4}$ inches. The redfish were preserved on board in 10% formaldehyde. At the laboratory, samples of scales and otoliths were immediately removed and preserved in 70% alcohol. The length of the fish was measured from the tip of the snout to a straight line between the outermost points of the tail.

In the course of 18 months a total of 19 samples was obtained. No fish below 6·7 cm. and very few individuals above 20 cm. were found. Many attempts were made to catch still smaller redfish by means of a special young-fish trawl fitted with a fine-mesh cover of a mesh-size of approximately $\frac{1}{2}$ inch. It is perhaps probable that no very small redfish were present in the localities from which the samples were taken. In all, 1860 specimens were examined. The sex could not be determined in 14 cases, but of the remaining 1846 individuals 47·7% were males, and 52·3% females.

Investigations on Scales and Otoliths

One of the first problems which arose in connexion with the present investigation was the selection of fish scales for age determination. A single fish was chosen, from which 148 scales were taken and examined in a binocular microscope. In addition, diagrams were made of scales taken at random from one side of one particular fish. Figure 1 shows some of the scale diagrams. No scale appeared to have more clearly defined zones than any other; in other words, it did not matter much from which part of the fish the scales were taken. On the other hand, scales with degenerate or deformed centres occurred very often. There is therefore no one particular scale which may be chosen as representative of the fish. In order that the data on growth-rates should be as reliable as possible, scales were taken from the same region of the body in all specimens, and those scales were preferred which had as much circular structure as possible. Presumably these scales were acquired at a very early age and should therefore give a maximal estimate of growth. The circular structures, or circuli, on scales from 5 fish were counted. One side of the fish was divided into regions as shown in Figure 2 and several scales were taken from each region. Large regions were chosen, in view of the many scales with deformed or degenerate centres. The counts of the circuli in scales from the different regions are shown in Table 1, in which the highest and lowest numbers of circuli found in each region are recorded. It may be seen from the table that scales with most circuli occur in Regions X–XIV.

The hyaline and opaque zones in the otoliths of redfish are believed to alternate regularly as in other fish and can therefore be interpreted as annual rings. In order to decide whether this is really the case, an examination was made of the condition of the edge of the otolith whether hyaline or opaque.

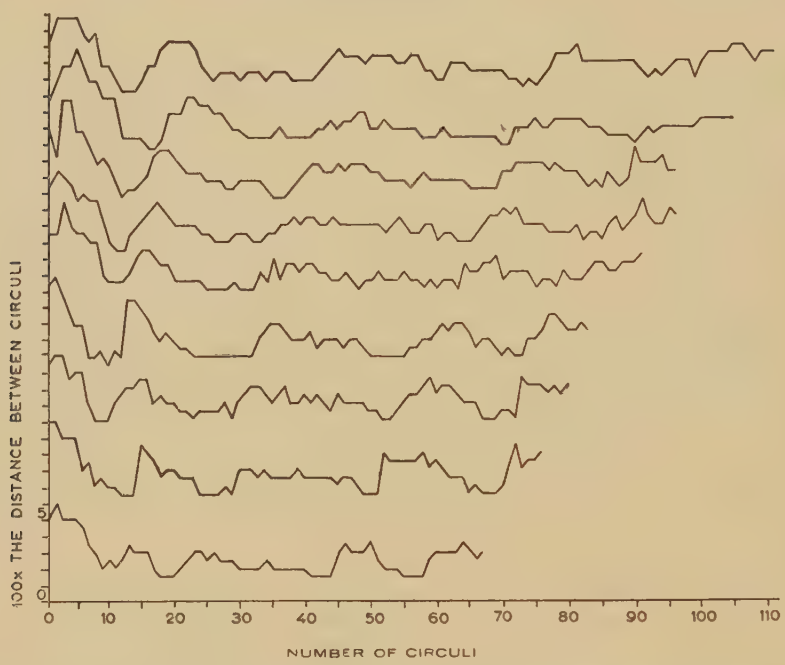

Figure 1. Scale diagrams for the scales of one fish. One unit on the vertical axis is equal to 0·0134 mm.

No continuous series of observations was made in one locality, and no definite statement can be made therefore about seasonal changes in the character of the edge of the otolith in a particular locality. However, by combining the samples from all localities, we may obtain a series of observations continuous in time, and this is shown in Figure 3. The number of otoliths with hyaline edges increases from September 1951 to January 1952. We find maximal numbers of otoliths with hyaline edges in January, February, March, and April. Thereafter the number of otoliths with opaque edges increases, reaching a maximum in June–August. From September to December 1952 the number of otoliths with opaque edges decreases, and a corresponding increase occurs in the number of otoliths with hyaline edges. Accordingly it may be concluded that the hyaline and opaque zones in the otoliths of the redfish alternate regularly with season, and that *one opaque and one hyaline zone are formed each year*. The opaque zone is formed in May–September, while the hyaline zone is formed in October–April.

As a further test of this conclusion, the seasonal sequence of narrow and broad zones in the scales of the redfish has been checked. Table 2 lists the results of an examination of 489 scales and otoliths from the same fish from which it may be seen that there is very good agreement between the otolith and scale readings, discrepancies occurring only in 5 cases. It may be said therefore that *the scales agree with the otoliths in regard to the state of their edges*. The data at hand indicate that the average time for the

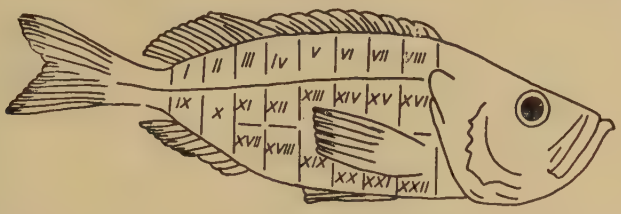

Figure 2. The regions of the body of the redfish from which scales were taken for examination.

formation of the opaque zones in the otoliths is July, and for the hyaline zones, December. On the Norwegian coast the usual time for spawning is May. The following system has been devised to indicate the age of a redfish:—

C.....	about 6 months old, but less than 1 year old									
C+H.....	–	1 year	–	–	–	–	1½	–	–	
C+H+O.....	–	1½	–	–	–	–	2	–	–	
C+H+O+H.....	–	2	–	–	–	–	2½	–	–	
C+H+O+H+O..	–	2½	–	–	–	–	3	–	–	

and so on; in this C denotes central zone; H, hyaline zone; and O, opaque zone.

The ages determined from otoliths have been checked by scale readings. Of the 489 scales read, 474, or 96·9%, showed quite clearly the same number

Table 1

Counts of circuli in redfish scales. Minimal and maximal numbers of circuli in scales from different body regions of the fish

Region	Total length of fish 13·1 cm.		15·2 cm.		18·0 cm.		19·5 cm.		24·7 cm.	
I.....	68	81	68	88	87	104	78	99	120	127
II.....	76	93	70	83	88	107	97	101	128	135
III	76	92	74	90	110	113	98	105	118	130
IV.....	65	81	68	82	100	104	87	100	107	125
V.....	72	81	58	79	74	103	83	103	105	111
VI.....	53	70	58	70	96	105	72	79	103	124
VII	57	68	50	59	62	96	56	84	96	118
VIII	51	64	70	72	67	103	56	78	96	106
IX.....	75	84	59	63	110	116	86	91	114	137
X.....	69	96	63	95	111	122	89	114	137	143
XI.....	94	100	91	99	115	130	103	129	133	146
XII.....	84	98	83	92	115	124	105	121	141	145
XIII	84	86	85	87	115	122	90	112	135	147
XIV	84	91	79	91	115	122	95	102	132	152
XV	74	76	71	90	105	119	80	98	116	130
XVI	69	76	75	85	102	107	89	94	126	130
XVII.....	71	89	69	83	111	117	81	96	94	98
XVIII.....	59	80	71	83	80	92	75	85	89	112
XIX	59	74	54	76	82	106	71	101	75	119
XX.....	53	61	53	74	67	105	73	97	87	111
XXI	45	61	71	76	62	102	58	75	81	116
XXII	59	61	60	65	83	101	51	81	92	119

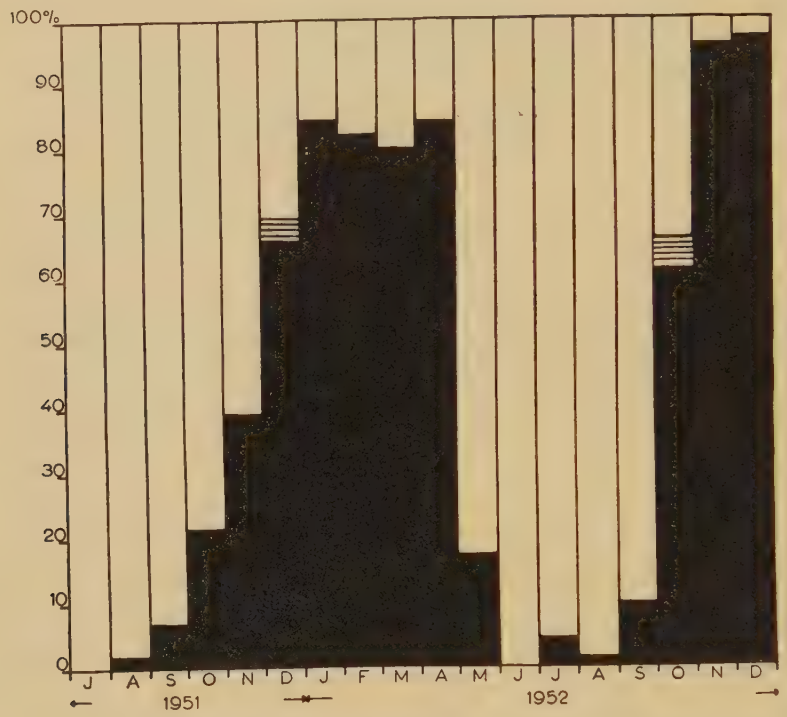

Figure 3. Monthly changes in the character of the edge of redfish otoliths.

□ = opaque edge
■ = hyaline edge
▤ = edge indeterminate

of annual rings as were seen in the corresponding otoliths. In 5 cases the estimates from scale and otolith disagreed; in 10, it was uncertain. On the basis of this test it may safely be stated that there is good agreement between both sets of readings. It may therefore be assumed that scales and otoliths form the same numbers of annual rings.

The samples at hand, were found to consist largely of a single year-class, that is, of fish hatched in 1949. The mean length of this year-class was computed for each month. In some cases the males proved to be longer than the females, while in others the females were the longer but *t* tests showed that the differences in size were not significant, and that males and females could be dealt with together. Figure 4 shows the length frequency and the age composition of males and females combined. In so far as it is possible to compare the ages and lengths in different samples, the agreement is very good. In the diagram for April–June a new year-class suddenly appears to be present. The explanation is, however, that at certain seasons fish of exactly the same age may have otoliths with edges of different character, and in consequence some may be recorded as belonging to the II-group, and some to the III-group.

Table 2

The state of the edge in scales and otoliths from the same fish

Date	Number examined	Scale circuli		Otolith edge		Number of deviations
		Broad	Narrow	Opaque	Hyaline	
1951						
July	85	85	0	85	0	0
August	165	162	3	161	4	1
September	87	82	5	81	6	1
October	7	7	0	7	0	0
November	10	6	4	6	4	0
December	14	2	12	4	10	2
1952						
January	10	3	7	3	7	0
February	12	0	12	0	12	0
March	15	1	14	1	14	0
April	9	0	9	0	9	0
May	11	10	1	10	1	0
June	10	10	0	10	0	0
July	9	9	0	9	0	0
August	7	7	0	7	0	0
September	8	6	2	6	2	0
October	10	6	4	6	4	0
November	9	0	9	0	9	0
December	11	1	10	0	11	1

Growth Investigations

To furnish an estimate of the mean yearly growth the lengths of single scales taken from 137 fish were measured. The results are illustrated in Figure 5, in which the points are seen to be concentrated about a straight line. The regression of length on age is given by the following equation:—

$$y = -0{\cdot}4402 + 0{\cdot}1489\,x$$

The equation is an approximate expression for the linear relationship between length of scale and length of fish.

The distance from the focus of the scale to the first, second, third, etc., annual ring was measured on a large number of scales from different individuals. The averages of these measurements were computed and marked off along the y-axis in a graph (Fig. 5). The corresponding values of x indicate the mean length of the fish at an age of 1, 2, 3, and so on, years. According to these figures the length of a redfish at 1 year old is 5·6 cm.; at 2 years, 8·4; at 3 years, 11·3; at 4 years, 13·1; at 5 years, 15·7; 6 years, 17·9; and 7 years, 21·5 cm. The figures indicate a growth of 5·1 cm. in the first year, as the young redfish is about 5 mm. in length when hatched. For succeeding years the observed increments are 2·8, 2·9, 1·8, 2·6, 2·2, and 3·5 cm. (seventh year). The annual increments in the 4th to the 7th year are based on very few measurements and can hardly be considered quite trustworthy. The increments for the first three years should be fairly correct, however, and the figures give us a broad idea of the amount of the annual growth.

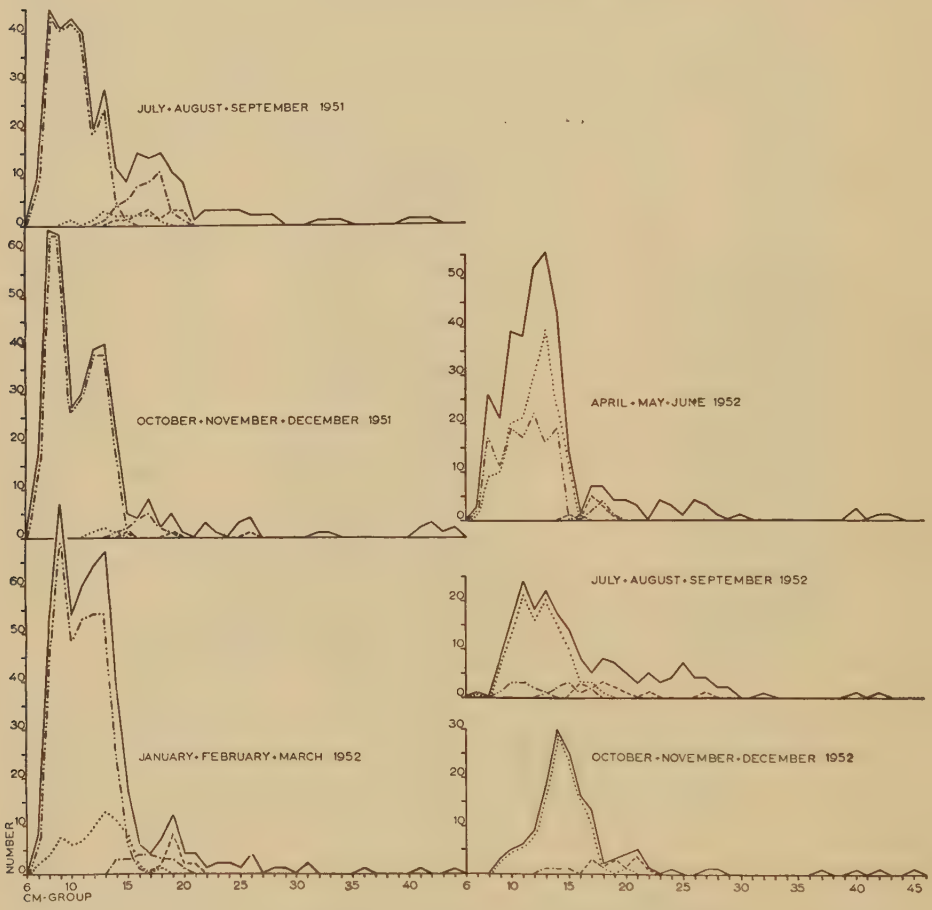

Figure 4. Length frequency and age composition in samples of males and females combined.

−.−.−.−.−.−. II-group
..... III-group
−.−.−.−.−.−. IV-group
———— V-group

Conclusions

The numbers of zones in the otoliths and in the scales of redfish show good agreement. The broad and narrow rings in the scales of young fish and the opaque and hyaline zones in the otoliths are usually equally distinct. Although secondary zones are found both in scales and in otoliths, they do not seem to be common. Length frequencies and individual age determinations in young fish show very good agreement. One opaque and one hyaline zone are formed each year. The present investigation indicates that the zones in the otoliths and scales of redfish are annual rings. One broad and one narrow zone in the scale, and one opaque and one hyaline zone in the otolith, constitute one annual ring. According to this interpretation, the redfish grows very slowly. Consequently large redfish must be very old.

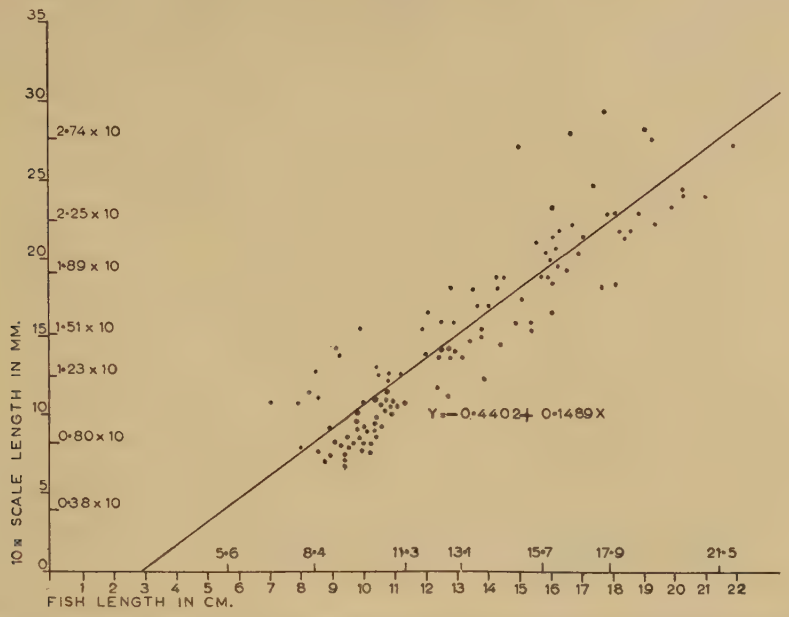

Figure 5. Measurements of scale length and fish length, with the computed regression line of length on age. The figures to the right of the vertical axis are the averages of the distances measured between the focus and the first, second, third, etc., annual ring. The figures above the other axis are the corresponding averages of fish length.

Summary

1. A group of 1860 redfish have been examined. The sex of 14 could not be determined, but of the remainder, 47·7% were males, and 52·3% females.
2. Of 148 scales taken from a single fish and examined in a binocular microscope, none showed particularly weak or strong zones. From scale diagrams prepared from the scales of one particular fish (Fig. 1), it seems that there is nothing to choose between scales in regard to clarity of zones.
3. To obtain data as reliable as possible for growth measurements the scales were taken from the same region in every fish. Presumably those scales with most circuli are acquired earlier than others and should therefore show maximal growth. The circuli on scales from 5 fish were counted (Table 1). Scales with maximal numbers of circuli were found below the lateral line, above and behind the posterior part of the pectoral fin (Regions X–XIV: Fig. 2). It was not possible to choose a particular scale because scales with deformed or degenerate centres occurred very often.
4. An examination was made of the state of the edge of the otolith — whether opaque or hyaline — at each season of the year. It was found that the edge was opaque from May to September and hyaline from October to April (Fig. 3). The opaque and hyaline zones in the otolith

are formed successively, in such a way that one opaque and one hyaline zone constitute one annual ring. To test these conclusions, the seasonal formation of the narrow and wide zones in the redfish scales was checked. The scales were found to agree with the otoliths in regard to the state of their edges (Table 2).

5. Age determinations from otoliths were checked by scale readings. Very good agreement was found, the scales and the otoliths of the same fish having identical numbers of annual rings.
6. The samples obtained consisted largely of one year-class, that of 1949. For this particular year-class *t* tests showed no significant difference between mean lengths of males and females in the different samples; males and females could therefore be dealt with together. The age-length relationship in the different samples seems to be quite uniform (Fig. 4).
7. An equation for the approximate linear relationship between length of scale and length of fish was computed (Fig. 5). Growth during the first year of life was found to be about 5·1 cm. The computed annual increments in the succeeding years were 2·8, 2·9, 1·8, 2·6, 2·2, and 3·5 cm. (seventh year). The computed annual increments from the fourth to the seventh year are not considered quite trustworthy.

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Destruction of Competitive Organisms on Artificial Oyster-Spat Collectors

By

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The larvae of various sedentary organisms are provided with a favourable settling surface when the limed tiles which are used as collectors in the Conway oyster-breeding tanks are removed to the sea in the autumn (Cole, 1938). Some species may grow rapidly, smother the oyster spat, and cause considerable mortality. In particular, solitary ascidians (*Ascidiella*, *Ciona*) and the sheet-forming compound ascidians (*Botryllus*, *Botrylloides*, and *Didemnum*) can be troublesome; barnacles and *Pomatoceros* are generally less so.

The report (Korringa, 1951) that it was possible to kill the slipper limpet (*Crepidula fornicata*) selectively in the presence of oysters, when they were immersed together in a dilute solution of a poison, suggested that it might be possible to devise a technique by which competitors might be killed without harming the oyster spat. Copper sulphate has been recommended for killing sedentary organisms on French oyster grounds (Anon., 1953), although the technique is not described.

It was realized at the outset of the work that any dipping which might be involved should be as rapid as possible, as the tiles were only exposed for a few hours at low water of spring tides. The experiments were designed to find a way of killing the majority of the competitors by taking the bundles of tiles off the racks shortly after they were uncovered, dipping them into the toxic solution, and replacing them on the racks. By keeping the dipping time short, only a small volume of toxic solution would be required. A thin film of poison would remain on the tiles until the tide came up about 2 hours later.

In the preliminary experiments tiles were dipped in a solution of 1 in 7,000 of mercuric chloride for 15 minutes and then stood in the dry for an hour. This was very effective as all the ascidians, barnacles, and Bryozoa, and most *Pomatoceros* were killed, and the oysters were left in excellent condition. As mercuric chloride is a dangerous chemical to handle, further experiments were made in which tiles bearing oysters and competitors were dipped for varying periods in different concentrations of commercial hydrated copper sulphate. The survival curve of *Ascidiella* in a typical experiment is shown in Figure 1. In this experiment 14 tiles which all bore approximately the same density of *Ascidiella aspersa* were selected. Two tiles were dipped for a few seconds into one of seven different concentrations of

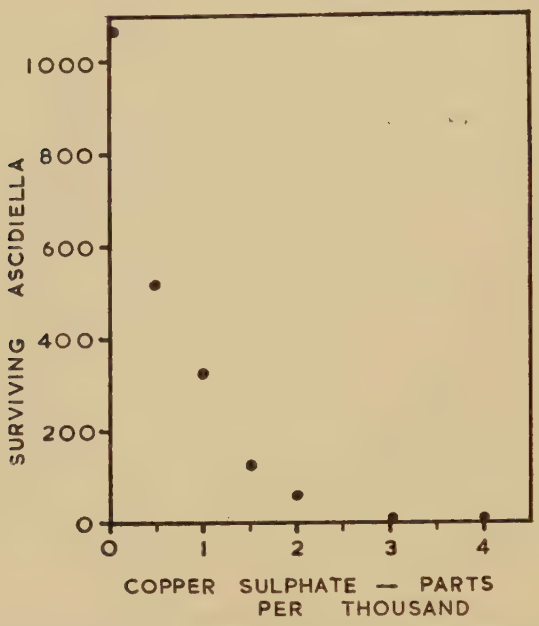

Figure 1. Numbers of surviving *Ascidiella* on oyster-culture tiles 10 days after treatment with various concentrations of hydrated copper sulphate.

copper sulphate and allowed to stand for one hour before being replaced in sea water. After 10 days the surviving ascidians were counted. It was impossible to count the oyster spat at the beginning of the experiment because of the dense covering of *Ascidiella*, but there was no observable mortality of oysters. Other experiments, in which competitors were less dense, showed that dipping did not cause an appreciable mortality of oyster spat. Further experiments confirmed that dipping the tiles into a solution of 4 parts per 1,000 of copper sulphate in sea water and then standing in the dry for 1 to 2 hours effectively removed the more serious competitors. Many tiles have been satisfactorily treated at Conway by this method. A dustbin makes a satisfactory dipping tank.

Summary

Experiments were made on the selective killing of competing sedentary organisms on collectors bearing oyster spat.

It was found effective to dip the collectors in a solution of 4 parts per 1000 of hydrated commercial copper sulphate and allow them to stand for 1 to 2 hours before they are covered with sea water.

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A Preliminary Study of Growth-Rate in Cockles (*Cardium edule* L.) in Relation to Commercial Exploitation

By

H. A. Cole

Introduction

Cockles as marketed in Britain vary greatly in size. Those reaching the London market from Barra, in the Outer Hebrides of Scotland, are uniformly large, often up to, or exceeding, 50 mm. in shell-length, whereas those from the great fishery in the Burry Inlet, South Wales, rarely exceed 30 mm. Cockles from Morecambe Bay, Lancashire, are intermediate. Such differences may result from basic variations in growth-rate or from varying intensities of exploitation. There is also the effect of minimum size regulations, which differ from one Sea Fishery District to another (in England and Wales) and affect the composition of the stocks remaining on the beds.

In recent years there has been intense exploitation of British cockle fisheries during a period of generally poor bivalve spatfalls. The combined action of these two factors has led to the belief that overfishing has occurred on some beds. This has led to an investigation of growth and spatfall and a reconsideration of minimum size limits on certain fisheries. The preliminary conclusions from these investigations are presented here; the full data will be given and more fully analysed in a later publication.

The Estimation of Age and Growth

It has long been known that cockles may exhibit on the shell a well marked series of rings; it was supposed that these represented annual growth-checks occurring during the coldest period of the year. Orton (1926), while he confirmed that rings were formed each year, also showed that disturbance rings were easily produced, e. g., by shifting bottoms, by the removal of cockles from their habitat for measurement, even though

they were returned within a few hours, or by marking the shell-edge with a file. These disturbance rings were generally much less well marked than true annual rings but could cause confusion. Stephen (1931, 1932), investigating the growth and spatfall of cockles on the south shore of the Clyde estuary, found well marked annual growth-rings, except in the first year. Kreger (1940) found little difficulty in separating year-classes on Dutch cockle beds, except on high banks where the beds were exposed for a long period. Fraser (1931) found well marked growth-checks in *Cardium corbis*, but noted that in old cockles the umbonal region might be worn smooth, obliterating the first winter-ring.

The conclusions from the present study are that annual growth-rings are usually to be clearly discerned but, from grounds on the south coast of Britain, where winter temperatures are relatively high and the cold period of short duration, growth-rings may be very faint or absent altogether in young cockles. The first growth-ring in particular is liable to be absent. In Poole Harbour, Dorset, a very favourable habitat, the third and subsequent rings are usually clear in practically all cockles but a high proportion show very faint first and second rings or none at all. Sufficient cockles have, however, been found with clear rings on all grounds examined to give an intelligible growth-pattern.

In South and North Wales and in Morecambe Bay growth-rings are usually very clear, as they are on cockles from Barra, Outer Hebrides. In individuals with many rings erosion of the shell at the umbo may be severe and may obscure the position of the first ring. Such heavily eroded cockles were found commonly in the Salcombe estuary, Devon; in many cockles the shell at the umbo was paper-thin and in some had actually broken through.

Under natural conditions disturbance rings are produced most commonly on exposed shifting bottoms where cockles may be buried or uncovered by gale action or strong currents at times of spring tides. It is a commonplace on the Burry Inlet and Morecambe Bay beds for cockles to be washed out of the soil into heaps, as streams and drainage channels over the flats change their course; alternatively, soil may be deposited over the surface of the beds from which cockles may have difficulty in emerging. Such violent environmental changes inevitably cause checks in growth which may be marked by a slight ring on the shell. Such disturbance rings are less deep and clearly marked than true annual rings and may not encircle the shell, fading away at the margins.

Since annual growth-rings may be found in at least a proportion of cockles on all grounds, it is possible in a large sample to separate the year-classes and to obtain an estimate of the growth which occurred over the previous 3 to 6 years, depending upon the age of the cockles examined.

Early post-settlement stages may be widely distributed by tides and currents (Baggerman, 1953) and older cockles may be washed out in quantity by gales or disturbed and carried away by streams draining comparatively flat areas. Such movements of older cockles can, however, usually be recognized and by careful selection of grounds reliable information can be obtained regarding growth in relation to tidal level and nature of soil.

In Britain cockles are rarely found below low-water mark of spring tides although they may flourish in mud at the bottom of certain enclosed lagoons. The main concentration occurs between mean tide level and low water of average neap tides. The reasons for this zoning are not clear. VERWEY (1952) suggests that light is important as influencing the settlement behaviour of the larvae, but gives no evidence in support. Predation by demersal and pelagic forms, e. g., flatfish, will be most severe on the lower levels of the shore, but predation by birds, e. g., oystercatchers (which have recently been shown by R. E. DRINNAN, of the Burnham laboratory, to take very large numbers) is likely to be most serious on those parts of the beds longest exposed. Whether larval cockles settle gregariously (see COLE & KNIGHT-JONES, 1949) is not yet known; such gregarious behaviour tends to result in the major concentration of young settled stages among the parent stock. As BAGGERMAN (1953) has shown, it is difficult to determine the initial settlement pattern since it may be quickly modified by post-larval transport by currents.

Growth-Rate in Relation to Environment

Tidal level

Although on the major cockle beds the greatest concentration of cockles occurs between mean tide level and low water, neaps, this is not the most favourable zone for growth. In a large series collected from widely dispersed stations on the Llanrhidian Sands, Burry Inlet, the cockles growing most rapidly were obtained from the lowest tidal levels. STEPHEN (1932) reached a similar conclusion. A comparison of growth-rates of 0-group cockles from "high", "medium", and "low" stations is given in Figure 1. These three stations were spaced over approximately 1,500 metres, with a difference in level of ca. 2 m. (in a tidal range of 8·5 m. at springs) between the high and the low stations.

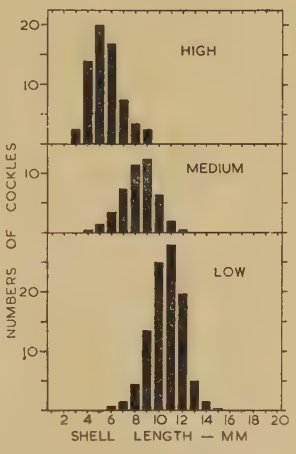

Figure 1. A comparison of cockle populations (0-group only) from three stations differing in height in relation to low-water level, from Llanrhidian Sands, Burry Inlet, South Wales.

In Poole Harbour, cockles are found living among the roots of rice-grass (*Spartina townsendii*), at the level of high water, neaps (GREEN, 1940). In this situation they can feed for only a limited period around high water and on poor neap tides may be uncovered for several days together. They are protected from desiccation by the dense covering of *Spartina*, but it is amazing that in this situation their growth should be only slightly less than that of cockles living at mean tide level and specimens up to 42 mm. in length have been found. What is even more surprising is that occasionally large specimens of *Paphia decussata* are found in the same situation. Figure 2

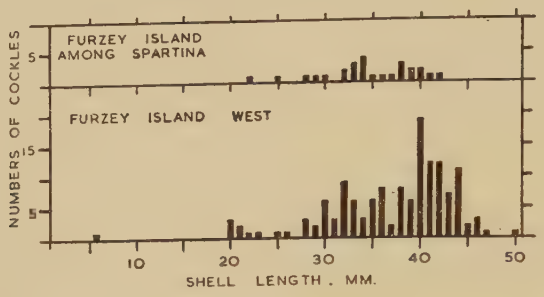

Figure 2. Cockles living among roots of *Spartina townsendii* at high water of neap tides in Poole Harbour, Dorset, compared with cockles from the shore nearby.

gives a comparison between the size and distribution of cockles (known locally as "floaters") taken from *Spartina* and those living at a normal tidal level on the flats alongside.

Nature of soil

Although the occurrence of cockle beds is generally associated with large estuarine flats of firm sand or muddy sand, such as those occurring in the Wash, the Thames estuary, the Burry Inlet, Morecambe Bay, or the Waddensee, cockles occur in other localities in a great variety of soils varying from soft mud to hard gravel and stones mixed with sand. In Poole Harbour, there is a great range of soils and cockles are found in all, if they occur at a suitable tidal level. Recent surveys of these beds, which are at present but thinly populated by cockles, allow a preliminary assessment of the effect of soil texture on growth. Water conditions throughout the area examined were very uniform and as the tidal range is very small (about 2 m. at springs), and the band of shore occupied by cockles very narrow, the degrees of exposure varied only slightly. The size distributions of a series of samples taken in May 1955 are plotted in Figure 3; it shows a considerable degree of uniformity in growth over the range of soils studied and suggests that growth is dependent on temperature and food conditions rather than on the nature of the bottom soil. In Poole Harbour exceptionally rapid growth occurs in all soils from very soft mud, on which a man of average weight in sea-boots sinks to his knees or deeper, to hard gravel and stones mixed with sand, from which it is impossible to collect cockles except with a strong rake or like instrument.

Conditions in Poole Harbour, however, are somewhat peculiar in that, due to the landlocked nature of the inlet and the relatively small tidal range, wave action on the shores is never severe. The coarse soils in the harbour occur in areas of relatively strong currents, the soft soils in areas of weak currents. KREGER (1940), from some analyses of current speeds over certain flats in the Waddensee, concluded that both very weak and very strong currents were unfavourable, the first because of exhaustion of food in the immediate vicinity of cockles lying densely together, the second through bombardment with transported particles, leading to closure of siphons and loss of feeding time.

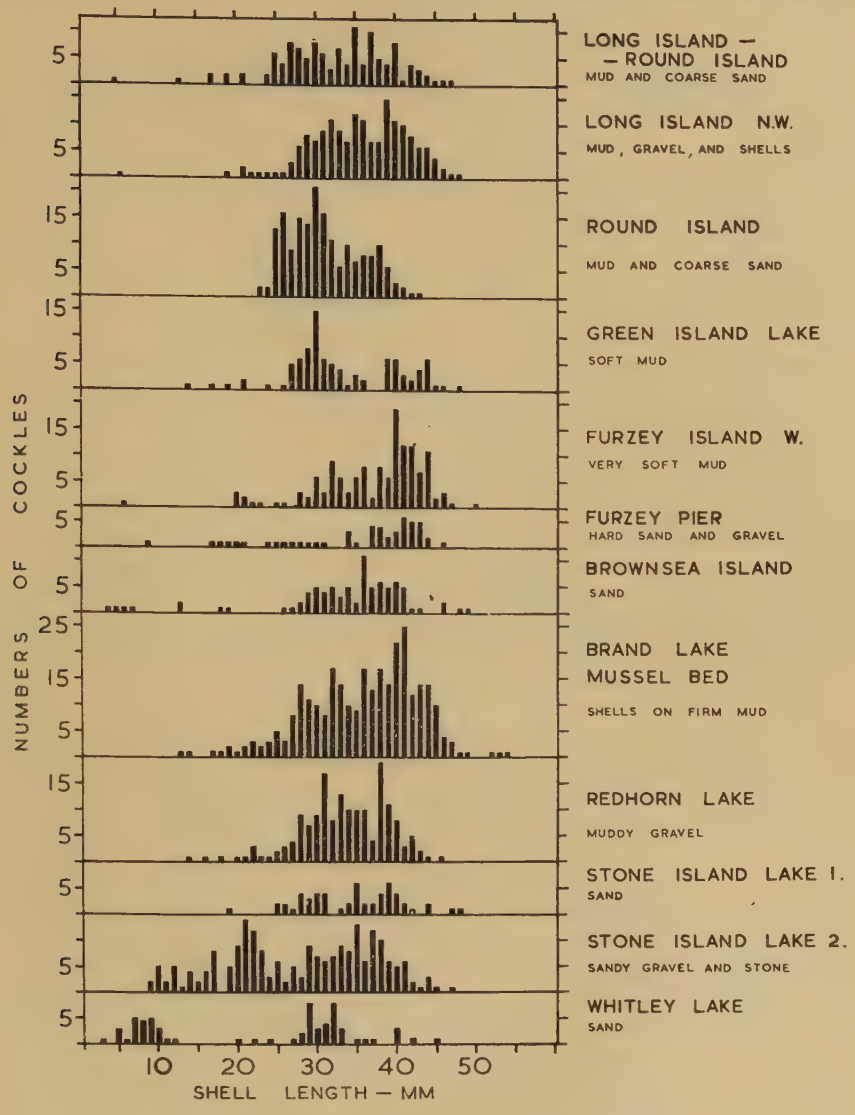

Figure 3. Size distributions of populations of cockles taken from a variety of soils in Poole Harbour, Dorset.

From a comparison of samples from habitats varying in degree of exposure to prevailing winds it seems that in situations commonly exposed to strong wave action the growth of cockles is slow and the maximum size small. This is well shown in Table 1, where two samples collected in exposed and sheltered situations in Essex are compared. In each case the soil was shell-gravel and sand with a little mud, and the tidal level was the same, viz., low water, neaps; average salinity was also similar in the two localities.

Table 1

Growth of cockles. Effect of exposure to wave action. The figures in brackets indicate the numbers in each sample

Locality	Situation	Date	1st ring mm.	2nd ring mm.	3rd ring mm.	4th ring mm.	5th ring mm.
Bradwell, River Blackwater, Essex	Exposed, W. to N.E.	August 1955	9·3(88)	20·3(74)	26·4(39)	28·8(19)	30·4(11)
Paglesham Pool, River Roach, Essex	Sheltered	August 1955	12·3(48)	25·1(40)	31·6(24)	34·8(11)	38·3(3)

Salinity

Cockles extend up-river in British estuaries some distance beyond the limit of toleration by oysters. In the Wareham Channel in Poole Harbour they are found up to Wood Bar Looe (a creek entering the main river estuary) where the daily range of salinity at neap tides in summer is from about 27‰ to 30‰ (GREEN, 1940). In this situation growth is somewhat stunted compared with the main beds in Poole Harbour where the summer salinity ranges from about 32‰ to 34‰ (Fig. 4). In such up-river situations cockle beds may be almost totally destroyed in winters which are either exceptionally cold or exceptionally wet. In consequence the maximum size reached is usually rather low. The dwarfing of cockles living in low-salinity water has been recorded by HAVINGA (1922) and others.

Density of Settlement

It is not easy to isolate the effect of density of settlement on growth from the effects of other factors such as tidal level, nature of soil, and exposure. During the course of a fairly comprehensive survey of the Penclawdd, Burry Inlet, cockle beds in April 1953, 21 stations were worked on the main producing area. The position of the mode of the group of cockles rising 2 years old (1 +), the group on which the fishery was based at that time, is clearly demarcated in the size-distribution curves in 19 of these samples. These stations have been grouped as "dense" (exceeding 1,750 per sq.m.) and "moderately dense" (less than 1,750 per sq.m.). The average density of all stations was 1,614 per sq.m., with a range from 241 to 4,350 per sq.m.

In the 7 dense stations the modes lay at 17, 18, 18, 18, 17, 19, and 19 mm.; in the 12 moderately dense stations the modes lay at 18, 18, 18, 19, 20, 18, 20, 19·5, 19, 19, 24, and 23 mm. If the stations are grouped in three zones according to their distance from high-water mark, the result is as shown in Table 2.

There seems to be a slight but definite slowing down of growth at the dense stations in each of the three zones. KREGER (1940) records an apparent density effect on the cockle bank known as Staart van Sheringhals in the Waddensee but this effect was not evident on other banks in the same area.

ORTON (1934) recorded cockle spat below 5 mm. in length at a density exceeding 100,000 per sq.m. on the Cark Sands in July 1933. Densities up

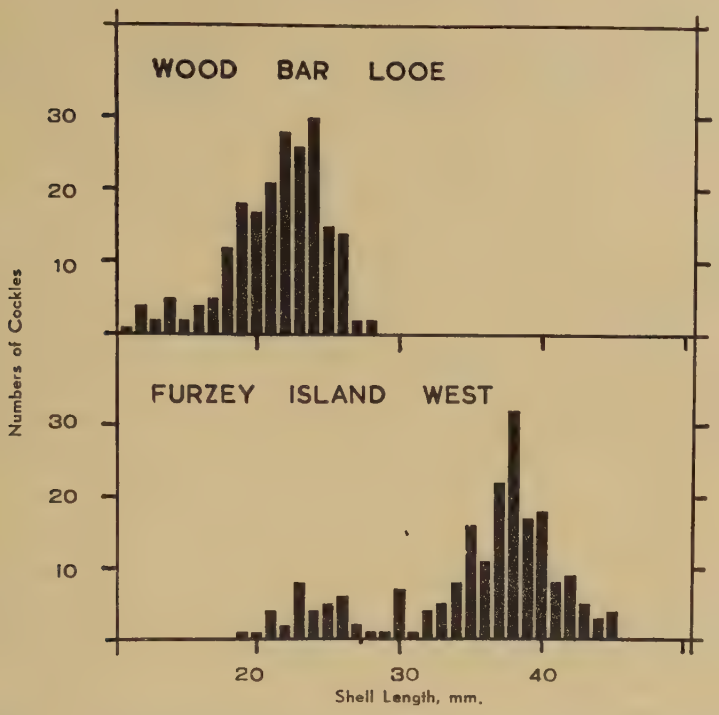

Figure 4. Effect of reduced salinity on the growth of cockles from Wood Bar Looe, Poole Harbour, subject to a strong flow of fresh water, compared with a typical station with normal salinity conditions. The bulk of the population at each station comprises 3- and 4-year-old cockles.

Table 2

Effect of population density on growth of cockles

Proximity to high-water mark	Moderately dense stations: Number of stations	Mean density per sq.m.	Modes mm.	Dense stations: Number of stations	Mean density per sq.m.	Modes mm.
Near.....	7	1,034	18, 18, 18 19, 20, 18 19	3	3,021	17, 18, 19
Mid	3	1,339	19.5, 19 19	3	2,533	18, 18, 17
Distant.....	2	465	24, 23	1	1,806	19

to 39,000 per sq.m. have also been described in Germany (WOHLENBERG, 1937), immediately after settlement, but these were rapidly reduced, so that at 2 years old only 800 cockles per sq.m. survived. In the present study the maximum density recorded was 6,142 per sq.m. on the Llanrhidian Sands, Burry Inlet, in December 1953; these were all 0-group cockles. Older cockles were found in the same area at densities up to approximately 2,300 per sq.m., representing a substantially larger volume of flesh, and therefore filtering

capacity, per unit area. Wright (1926), when he examined the same grounds in 1923, obtained 5,649 0-group cockles per sq.m. at one station so that spatfalls at this density must occur fairly frequently. Actual settlement densities must be considerably higher since Wright's estimate was made in April and that from the present study in December. Wohlenberg (1937) showed that losses up to nearly 90% may occur in the first six months after settlement.

Wright recorded no less than 8,000 one-year-old cockles per sq.m. on the Maplin Sands, Thames estuary, with an average length of 13·9 mm. At such densities there is a solid pavement of cockles with little unoccupied space and it must be concluded that competition for food severely limits growth. Conditions for the spread of epidemic diseases would seem to be very favourable (see Korringa, 1955) but only one instance of unexplained mortality in cockles has been recorded (Orton, 1934). A similar mortality among *Amphidesma ventricosum* in New Zealand has been recorded by Rapson (1954).

Annual growth increment

Samples of cockles have been examined from Barra (Outer Hebrides), Morecambe Bay, several localities in North Wales, Burry Inlet (South Wales), Milford Haven, Fal estuary, Salcombe, and Poole Harbour. Average size at the time of formation of first, second, and third growth-rings has been determined for each locality; the results are presented in Table 3. Growth is very rapid in the Upper Fal, at Barra, in Poole Harbour, and in North Wales; it is intermediate at Salcombe and in Morecambe Bay, and slow at Milford Haven and the Burry Inlet. Comparison of size reached at the first winter ring is not profitable since this may depend to a substantial extent upon time of settlement. The latter may extend from May to early September. It has been observed that late-set cockles may be less than 5 mm. at their first winter (see also Stopford, 1951) but grow rapidly in favourable areas during their second year.

The reasons for these variations in growth-rate are not clear in all cases; comparison is made difficult by the great differences in the nature of the habitat. Beds located on firm, gently shelving sand flats are found in Morecambe Bay, Burry Inlet, Lavan Sands, and Milford Haven. Freshwater influence is much greater in Morecambe Bay and the Burry Inlet than on the North Wales beds or in Milford Haven, and this seems to be correlated with reduced growth-rate. The beds at Morecambe and in the Burry Inlet are considerably exposed to the prevailing south-west winds and this, it is suggested, adversely affects growth in these two areas. At Barra the beds are sheltered from westerly winds.

Density is highest in the Burry Inlet where the growth-rate is the slowest so far recorded. Milford Haven, however, is little better, yet the bed from which the sample was taken lies on the inner edge of a large area of flats in a situation of practically full salinity where there is a rich and varied fauna. The density of cockles did not exceed 1,000 per sq.m. and the cause of the poor growth remains obscure.

Table 3

Growth of cockles. Size at the time of the formation of first, second, and subsequent winter rings. The figures in brackets are the numbers measured in each sample

Locality	Date	Mean length, mm. 1st ring	2nd ring	3rd ring	4th ring	5th ring	6th ring
Tolverne Reach, River Fal, Cornwall	July 1953	15·9(94)	28·5(94)	32·7(89)	–	–	–
Poole Harbour	July 1954	12·4(101)	25·8(47)	36·1(18)	39·9(15)	41·7(11)	45·0(5)
Barra, Outer Hebrides	Nov. 1953	15·7(69)	25·7(58)	28·5(6)	–	–	–
Barra, Outer Hebrides	May 1954	15·1(106)	24·5(106)	29·0(81)	31·3(48)	34·1(36)	38·1(12)
Lavan Sands, Menai Straits, North Wales	March 1950	10·9(92)	23·4(79)	28·2(54)	31·1(21)	31·60(5)	33·70(3)
Lavan Sands, Menai Straits, North Wales	Nov. 1953	11·4(10)	25·0(13)	–	–	–	–
Cartmel Wharf, Morecambe Bay, Lancashire	Jan. 1954	8·0(97)	21·0(97)	24·4(97)	–	–	–
Blanks Mill, Salcombe, Devon	Apr. 1955	9·5(20)	19·4(38)	24·5(12)	–	–	–
Llanrhidian Sands, Burry Inlet, South Wales	Aug. 1949	9·5(106)	17·9(104)	24·3(9)	–	–	–
Martin Haven, Milford Haven, Pembroke	May 1955	9·3(80)	17·9(62)	23·1(31)	–	–	–

Although the cockles from the river Fal were the largest at the time of the formation of the second ring, their growth increment in the year after settlement averaged 12·6 mm. compared with 13·4 mm. at Poole. In the next season the Fal cockles increased in length by 4·2 mm. only, whereas those at Poole gained 10·3 mm., and a further 3·8 mm. in the following year. Density may have exerted some effect, however, as the Fal bed was described as "very dense" by the collector, whereas at Poole cockles were sparse. The common feature of the two areas is shelter from severe wave action.

Wave action is heavy at times, particularly during late autumn, in both Morecambe Bay and the Burry Inlet and seems to be a factor leading to severe checks in growth and low average annual growth increments. The Salcombe sample, from a sheltered creek, is anomalous in this respect and one can only conclude that some adverse environmental factor, so far unrecognized, was limiting growth. Possibly the occurrence of severe erosion of the shell, noted above, may be the result of acid conditions in the soil, which also lead to poor growth.

Sea Temperature

Low winter water temperatures seem to result in a severe check to growth and poor average annual growth increments in comparison with areas where water temperatures are higher and severe cold is unusual. The cockles are larger and grow faster at Barra, in the river Fal, and in Poole Harbour than they do in Morecambe Bay or South Wales. North Wales is intermediate. There seems, therefore, to be a correlation with the duration and intensity of winter cold. Very low winter sea temperatures are not recorded in North Wales or off the Outer Hebrides or the south-west coast of Britain. The Milford Haven sample is again anomalous since this is a deep inlet into the relatively mild, frost-free peninsula of Pembroke.

Of the beds examined, Poole Harbour probably experiences the highest average summer temperature and it is not surprising to find this reflected in a high growth-rate. On the other hand the low summer temperatures off the Island of Barra in the Outer Hebrides do not check growth, as cockles from these beds reach an exceptional size.

Duration of Life and Maximum Size

The largest cockles obtained were from the Island of Barra and from certain west Scottish lochs. A single live individual of shell-length 64 mm. was collected from Loch Craignish, Argyll, and several fresh shells of similar size were seen. This giant cockle showed clearly marked rings at 12, 25, 36, 47, 52, 54, 56, 57, 58, 59, 60, 61, 62, and 63 mm., which indicate that it had reached an abnormally large size by virtue of both a high growth-rate and a long life.

A commercial sample from Barra, sent to me by courtesy of Dr. H. J. Thomas, contained cockles up to 51 mm. A cockle of 51 mm. from Barra showed rings at 50, 49, 48, 47, 45, 43, 40, 37, 32, 23, and 12 mm., which gives annual growth increments of 11, 9, 5, 3, 3, 2, 1, 1, and 1 mm. respectively after the formation of the first winter ring. Samples from Poole Harbour include individuals up to 54 mm.; in that area those below 30 mm. are not usually taken by bona-fide cockle fishermen. Such cockles show from 7 to 9 rings but growth increments are very small at this age and rings at the edge of the shell are not easily distinguished.

On the Lavan Sands in Menai Straits, North Wales, the cockle beds are virtually unexploited, and the maximum size and age reached are therefore not influenced by commercial gathering. As can be seen from Table 2, there is a marked decline in length increment after the third season. During recent surveys the largest cockles found were 45 mm. in length; competition was not severe since the maximum density recorded did not exceed 100 cockles of all sizes per square metre. On unexploited beds at Bradwell, Essex, in an exposed situation, it was rare to find individuals over 35 mm.; annual growth increments after the third year were very small (Table 1) and after the fifth year generally resulted in an increase in tumidity without a measurable increase in length.

Reference to Table 2 shows that where cockles reach a large size they do

so in the main by virtue of continued rapid growth in their third and subsequent seasons. The average growth increments between the second and third rings in Poole Harbour (large) and Morecambe Bay (small) cockles were 10·3 mm. and 3·4 mm. respectively. Continued growth of large cockles is presumably related to the amount of competition for the available food supply, but the possibility of inherent differences in growth pattern should not be overlooked.

On the large commercial fisheries of South Wales and Morecambe Bay cockles showing more than four rings are very scarce and none has been found with more than six rings. KREGER (1940) mentions that he never succeeded in counting more than four winter rings clearly distinguishable in Waddensee cockles. *Cardium corbis* (FRASER, 1931) does not survive beyond seven years in British Columbia.

Growth-rate in relation to commercial exploitation

The accepted method of conserving cockle supplies on beds in England and Wales is to fix a minimum size limit below which cockles may not be removed. Most local Sea Fishery Committees fix such a size limit by bye-law, usually prescribing a gauge with a square aperture through which the cockles taken must not pass. Minimum sizes vary slightly from place to place, the largest being a gauge with a square hole with a side of 1 inch (25·4 mm.) and the smallest one with a side of $\frac{11}{16}$ inches (17·5 mm.). The lengths of cockles which pass through these gauges vary somewhat with the tumidity of the shells, young quick-growing cockles being less tumid than older slow-growing cockles of the same shell-length. A square gauge of side 17·5 mm. retains most cockles above 21 mm. in length and one with 25·4 mm. side those above 30 mm. Tables 1 and 3 show that cockles 21 mm. in length have two rings (rising 2 years old) in South Wales, Morecambe Bay, and some parts of Essex, but only one ring in most other localities. Cockles of 30 mm. are over 2 years old in all localities and over 3 years old on many beds.

Conservation aims at retaining on the beds in their second year (the first major breeding period) the bulk of the stock of cockles. With such an accessible animal the policy appears to be sound, regard being had to the very limited information about replacement rate and natural mortality. The application of this policy can be illustrated by recent changes in the minimum size applicable to the Burry Inlet beds. This fishery showed symptoms of intense exploitation in that large cockles were almost entirely absent and yields fluctuated violently from year to year in consequence of dependence on a single year-class (those rising 2 years old) and irregular spatfalls. Investigation showed that with the minimum size limit then enforced (a gauge with square aperture of side $\frac{5}{8}$ inch (16·0 mm.)) it was theoretically possible to remove over three-quarters of the breeding stock of 1+ cockles before the peak of the breeding season had been reached. In the absence of any significant number of older cockles this was considered undesirable and the minimum size limit was raised to $\frac{11}{16}$ inch (17·5 mm.). The effect of this in conserving the breeding stock is shown diagrammatically

in Figure 5. In this fishery cockles of the group rising 2 years old average 19 mm. in April, when growth recommences after the winter, and increase in length by 6 mm. on the average during the following summer and autumn before growth is again checked in October. Thus it is possible, by assuming a steady growth-rate, to draw six curves to represent the state of the population of cockles of this year-class with modes at intervals of 1 mm. The breeding season and the old and new size limits are also shown in Figure 5. It can be seen that an increase in the minimum size limit of only $\frac{1}{16}$ inch (1·5 mm.) has a material effect in conserving breeding stock. After the change, the yield from the fishery has steadied and spatfalls appear to be more uniform. Clearly such changes can only be made on the basis of full knowledge of local growth-rates.

Discussion

It has been shown that growth in cockles is influenced by sea temperature, salinity, tidal level, exposure to wave action, food supply, and density and time of settlement. The effect of nature of soil has not been fully investigated but appears to exert less influence than was expected from a study of the literature. Cockles are shown to thrive in a great variety of soils and are not restricted, as KREGER (1940) reported, to clean muddy sand. The "normal" habitat, comprising large estuarine sand flats, is shown to be less favourable for growth and survival than sheltered areas with soft soils in creeks and inlets less exposed to wave action or greatly reduced salinity. The level on the beach which carries the densest population is less favourable for growth than lower down on the shore; the reasons for the observed zoning are not clear but it is probably the result of larval preferences modified by current transport and predation by flatfish. Since cockles are susceptible to destruction during both exceptionally hot (ORTON, 1934) and exceptionally cold weather (SMIDT, 1944) it follows that mass settlement on the middle regions of the shore, as normally observed, leads to increased mortality from these causes when compared with settlement on the lower shore where growth would also be superior. One cannot avoid the conclusion that despite its success as a littoral animal, the cockle is somewhat ill adapted to its environment in that the behaviour of the larvae at the time of settlement tends to result in vast accumulations of seed cockles in situations which do not lead to rapid growth and a high rate of survival.

The most favourable areas for the settlement of cockle spat in Britain are the large sandy estuaries (Thames, Burry Inlet, Wash, and Morecambe Bay), as judged by the regularity and extent of their production of market cockles. Information regarding growth-rate in the Thames estuary and the Wash is sparse but in Morecambe Bay and the Burry Inlet growth has been shown to be much slower than on the soft soils in southern estuaries and inlets, such as Poole Harbour. There is therefore a possibility of profitable transplantation of seed cockles from the sandy exposed estuaries to the sheltered areas, the system recently developed with great success in Malaya (SOONG, personal communication). Initial small-scale transplantations from the Burry Inlet to Poole Harbour have already been made and if successful will be followed by commercial-scale operations.

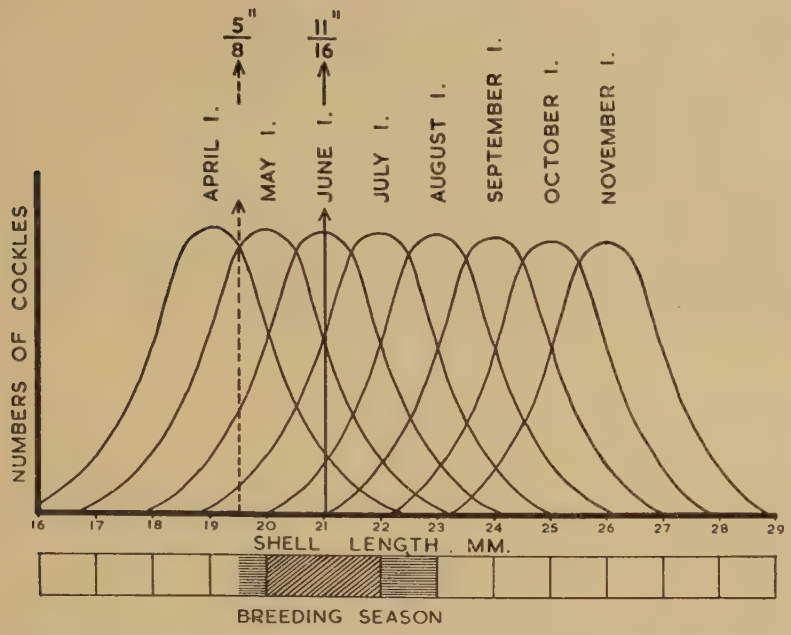

Figure 5. An analysis of growth and breeding on the Burry Inlet beds in relation to commercial exploitation. The size distribution of the group of cockles rising 2 years old is shown at the commencement of each month from April to November. The effects of using the present ($\frac{11}{16}$-inch square hole) and past ($\frac{5}{8}$-inch square hole) legal minimum size gauges are shown.

Summary

Cockles from British beds usually show well marked annual growth-rings on the shell, from which their age and growth can be determined. The first winter ring may be faint or absent in cockles from areas in which winter temperatures are relatively high.

The growth of cockles is greatly influenced by the tidal level at which they occur. Although the major concentration of cockles on most beds lies between mean tide level and low water, neaps, growth is much faster towards low water, springs.

Soil texture appears to have little direct effect on shell growth. Large cockles may often be found in soft soil, but their rapid growth usually results from freedom from exposure to wave action, which is shown to limit growth.

Low salinity due to river discharge tends to depress growth-rate severely.

Growth is less rapid on very densely settled beds of cockles, but in areas of considerable water movement densities of over 1,000 per sq.m. may exist without a marked depression of growth-rate.

Annual growth increments were found to differ substantially in samples examined from a wide variety of habitats in Britain and were low on the

large commercial beds in Morecambe Bay and South Wales. The probable causes of the observed variation are discussed.

Low winter water temperature seems to result in severe checks to growth and poor average annual growth increments in comparison with areas where water temperature is higher and severe cold is unusual.

Duration of life and maximum size reached vary widely and it is suggested that there may be inherent differences in growth pattern.

The importance of a knowledge of growth-rate in relation to commercial exploitation and conservation is illustrated by reference to the recent change in the minimum size limit regulating the collection of cockles from the beds in the Burry Inlet, South Wales.

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Reviews

R. R. Long. "Some aspects of the flow of stratified fluids. I. A theoretical investigation;" "II. Experiments with a two-fluid system"; "III. Continuous density gradients". Tellus, **5**, 1, pp. 42–58, 4 figs. Stockholm, 1953: *Ibid.*, **6**, 2, pp. 97–115, 22 figs. Stockholm, 1954: *Ibid.*, **7**, 3, pp. 341–357, 15 figs. Stockholm, 1955.

In these three papers Dr. R. R. Long has begun an investigation into the flow of a stratified fluid over an obstacle on a horizontal floor. The theoretical analysis is for an oncoming stream of uniform velocity, which produces downstream a variety of non-uniform conditions. The experimental work was done in a long laboratory tank which had still fluid in it, firstly with a density discontinuity, and secondly with a continuous density gradient. A low, well streamlined obstacle extending across the tank was then pulled along the bottom and the resultant flow over it made visible by photographing solid particles in the fluid. The phenomena observed depend mainly upon the internal Froude number, $F_i = U(g\frac{\Delta\varrho}{\varrho}H)^{-\frac{1}{2}}$ where U is the speed, H the total depth of fluid, $\Delta\varrho$ is the density difference between the layers and ϱ the mean density.

At high F_i the flow over the barrier was symmetrical, the fluid rising ahead and falling behind it to its original condition (break-away does not occur). At lower F_i, however, a variety of wave-like phenomena occurred in the streamlines downstream, and the flow was distinctly unsymmetrical. Layers of higher speed fluid were sometimes present between layers of lower speed, and under some conditions a hydraulic jump occurred.

Although Long is using his work to explain the meteorological phenomena of "lee waves" in the atmosphere downwind of hills, the use of a liquid in the experiments immediately suggests that the results can be applied to stratifications in shallow seas. To some extent, the reviewer thinks that they

can, and particularly to problems in tidal estuaries. They are unlikely to be of much value yet for examining wind-driven currents in the open sea, which cause an upper layer to slide over a lower layer. On the other hand, tidal movements such as those in estuaries sometimes cause the whole depth of water to move more or less uniformly, even if there is distinct stratification. These streams, passing over a bar at the mouth of the estuary, may give the internal waves and discontinuities shown in the experiments.

It would seem that if the waves occur at all, they will do so when the current velocity is quite low, when the stratification may be rather marked. At the higher current speeds, the turbulence in the stream reduces the stratification so much that F_i is high and the flow passes over the obstacle without giving waves. Unfortunately, however, low speeds and stronger stratification tend to favour relative motion between layers, a case not yet studied by LONG.

Whatever the limit to the application of the present experiments, any future investigator into interfacial waves will find it essential to refer to Dr. LONG's work. It is to be hoped that his future programme of research will include some of the more difficult relative motion problems.

J. R. D. F.

J. R. Lumby. "The depth of the wind-produced homogeneous layer in the oceans". Min. Agric., Fish., & Food, Fish. Invest., Ser. II, **20**, 2, 12 pp., 9 figs. London, 1955.

Mr. LUMBY makes practical use of the steady-state theory of ROSSBY and MONTGOMERY for the depth of the ocean mixed layer and the British Meteorological Office statistical wind summaries for each Marsden square (10° Lat. by 10° Long.) of all oceans in latitudes below 60°. The results are in the form of quarterly charts of mixed-layer depth distribution over all ocean areas for which statistical wind data exist. This is the equilibrium distribution of mixed layer depth which would result from the third quartile wind force. This computation excludes all other factors besides the wind which could assist in forming or maintaining the mixed-layer depth. Mr. LUMBY clearly states the limitations of his undertaking.

The ROSSBY and MONTGOMERY relationship used is $h = K \operatorname{cosec} LW_0$ where

h is mixed layer depth
K is coefficient of proportionality
L is latitude
W_0 is surface wind force

Stability of the water in the surface layers is considered only on a seasonal and latitudinal basis since K has been determined by ROSSBY and MONTGOMERY at various latitudes for the four seasons. Mr. LUMBY uses these estimates of K in his computations. It is interesting to note that the ratio between K cosec L at 15° N. and at 55° N. is nearly equal to the ratio of the

chart values of mixed-layer depth at the same latitudes in the North Atlantic Ocean in summer and spring.

Lat.	Winter K cosec L	Summer Spring K cosec L	Autumn K cosec L
15°	8·3	7·0	7·7
55°	3·8	2·75	3·4
	$\frac{K \text{ cosec } 15°}{K \text{ cosec } 55°} = 2{\cdot}2$	$\frac{K \text{ cosec } 15°}{K \text{ cosec } 55°} = 2{\cdot}5$	$\frac{K \text{ cosec } 15°}{K \text{ cosec } 55°} = 2{\cdot}3$
	$\frac{h_{15}}{h_{55}} = 1{\cdot}5$	$\frac{h_{15}}{h_{55}} = 2{\cdot}0$ (spring) $2{\cdot}3$ (summer)	$\frac{h_{15}}{h_{55}} = 1{\cdot}5$

As Mr. LUMBY points out, K cosec LW_0 would yield mixed-layer depth contours parallel to circles of latitude if there were no longitudinal variation in wind force. This condition is approached most closely in spring and summer. The formula provides only a slight skewness of contours. In autumn and winter the stronger and more variable (longitudinally) wind patterns in middle and high latitudes result in considerable departure from zonal mixed-layer depth distribution.

A rather surprising feature of the charts is the slope of the contours toward deeper mixed-layer depth from east to west in the equatorial Atlantic. It is known that the mixed-layer depth is deeper on the west side of the Atlantic, and it is thought by SVERDRUP and DEFANT[1]) that this is due to the major current systems in that region. Thus the slope of the contours could be as shown even with a uniform wind field in zonal direction. Since the ROSSBY and MONTGOMERY theory does not apply easily to equatorial regions, it might be possible to relate the mixed-layer depths in equatorial regions directly to the current systems.

Using only the wind statistics and an average stability parameter, Mr. LUMBY derives charts of average mixed-layer depth, which are in remarkable agreement with the world mixed-layer depth charts based on hydrographic and bathythermograph data such as those in the "Application of Oceanography to Subsurface Warfare" (National Research Council, 1951). Whereas the absolute values of mixed-layer depth are not in agreement with observations in some areas, the general patterns of the derived charts are quite realistic. In addition Mr. LUMBY points out other factors which must be studied in order to gain a more complete knowledge of the physical processes which take place in the surface layers, i. e., stability and advection. It has been carefully pointed out that the derived charts present a broad average picture. Mr. LUMBY's Figures 6 and 7 show the variability of the mixed-layer depth for the months of May to November in two areas in the North Atlantic.

Robert A. Gilcrest

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[1]) *The Oceans* (SVERDRUP, JOHNSON, and FLEMING) pp. 633, Prentice Hall, 1942.

G. T. D. Henderson. "Continuous plankton records: the young fish and fish eggs, 1932–39 and 1946–49". Hull Bull. Mar. Ecol., **3**, 24, pp. 215–252, 10 figs., 8 pl. Hull, 1954.

From pre-war and post-war Plankton Recorder material, the distributions of fish eggs and young fish in the North Sea have been examined. In general the eggs were not identified and the young fish were grouped as Clupeidae, Ammodytidae, Pleuronectidae, Gadidae, and Scombridae. Plates XXI and XXII show total Clupeidae averaged for each of the twelve months of the year, and the distribution of young fish corresponds in time and space quite well to the positions of the known spawning grounds of the herring; there is, however, one patch of larvae in the Southern Bight in July 1947 which were probably sprats or pilchards.

Charts of the Ammodytidae show three groups; firstly, a patch in spring between the Humber and the Friesian Islands, secondly, a spring patch off the Scottish coast, and thirdly, a patch south of the Dogger in July and August. The charts of Pleuronectidae show a patch off the Friesian Islands which probably originated in part from the Southern Bight spawning but also in part from the "Heligoland" spawning.

When all fish eggs are grouped by months into the three main regions of the North Sea, north-east, north-west, and southern, a sharp division between spring spawners (February–April) and summer spawners (June and July) is observed.

One of the most interesting results of this paper is a relation between the density of fish eggs in the southern North Sea and the British catch per 100 hours of all demersal fish in Area IV from 1932 to 1939 and from 1946 to 1949; when the data are plotted as a time series, a parallelism is shown. The remarkable points are, firstly, that a slight rise in the catch per unit of effort in 1938 and 1939 occurs also in the density fish eggs, and secondly, that the sharp decline in catch per unit of effort after the war is accompanied by a sharp decline in egg density.

The numbers of eggs in the southern North Sea are mainly from cod and plaice, whereas the catch per unit of effort is an estimate for all commercial fish from the whole North Sea. One might expect more fish eggs in 1946 than in 1939 or 1949, if fish stocks benefited from six years of war, and a reduction of catch per unit of effort to a half is accompanied by a reduction in egg density of about three times. In the pre-war period, however, a change in egg density of up to three times is only accompanied by change in catch per unit of effort of between 90 and 120 units. The implication is that each estimate is a sensitive index of abundance even when the eggs and the fish are possibly different.

A comparison is made between the annual fluctuations in numbers of young fish in the North Sea and the fluctuations in numbers of young fish at International Station E1, excluding clupeids and ammodytids. As the numbers of young fish off Plymouth go down, so those in the southern North Sea go up. The reality of this inverse relationship is in itself doubtful, and the author's suggestion that it might be due to gross change in water condition seems very unlikely.

D. H. C.

F. Gessner. "Hydrobotanik: die physiologischen Grundlagen der Pflanzenverbreitung im Wasser. I. Energiehaushalt". Veb. Deutscher Verlag der Wissenschaften. Berlin, 1955.

The first volume has been published of a handbook which in all probability will become one of the most valuable tools for all who work with aquatic plants, both planktonic and sessile, either freshwater or marine. In all, 3 volumes are planned. The first deals with energy metabolism. In the next volume, which should appear in 1957, the plants are considered in relation to the chemistry of the water.

The author, Professor GESSNER, at present holds the Chair of Plant Physiology at the University of Munich, and is very well qualified to write a book of this kind. He has worked successfully both as a marine biologist and as a limnologist, and has dealt with the physiology of both phanerogamic aquatics and plankton algae. GESSNER is able to write in a style which is impressive and at the same time is easily read by a non-German. He shows himself to be a brilliant exponent of one of the finest traditions of German science in his ability to master the literature of all western countries, an ability characteristic of relatively few of the authors of textbooks in these days.

It is impossible to present a full summary of the first volume: the index alone covers 3 pages. We may, however, mention the main sections as follows:— I. Light and the distribution of plants in the water; II. The influence of ultra-violet radiation on aquatic plants; III. Radiation of heat as an ecological factor; IV. The influence of hydrostatic pressure; V. The ecological importance of water movements; VI. The interrelation of light, temperature, and water movements.

In view of the complexity of the subject generally, a subject index is badly needed. We may of course find such an index in the final volume, covering all three volumes, but for this we have to wait.

The advantages to be gained by describing an aquatic botany, instead of merely a marine or a freshwater botany, become more and more evident from reading GESSNER's book. There is every reason to believe that this realization will be a most stimulating experience for many limnologists and marine biologists, especially for those who have tended to specialize too much. The joint organization of limnologists and oceanographers set up in the U.S.A. may be mentioned in this connexion; it is an event of equal importance.

GESSNER's book is written in German. To those who are not able to read this language, I can only say that their qualities as biologists are limited thereby. Why not start studying German now? Let GESSNER's book be the incentive! The trouble will be repaid many times. Moreover, scientific papers in a foreign language are not as a rule difficult to read.

E. Steemann Nielsen

W. F. Royce & H. A. Schuck. "Studies of Georges Bank Haddock. Part II. Prediction of the catch". U.S. Dept. Int., Fish & Wildlife Serv., Fish. Bull., 90, pp. 1–6, 1 fig. Washington, 1954.

Haddock on Georges Bank are available all the year round, and have constituted an important part of the catch of the New England fishermen for the last 25 years. The quantity landed annually has fluctuated considerably from as little as 50 million pounds (1934) to as much as 223 million pounds (1929). Such fluctuations have always been a nuisance, particularly when unexpected, so that any elimination of uncertainty by means of predictions can be of value to the industry.

In this paper, the authors have described a procedure for predicting the catch of haddock on Georges Bank. Their method is based on the assumption that the catch of a year-class during any particular year could be related to three other variables, viz., the amount of fishing during that and the preceding year, and the quantity of the same year-class landed in the preceding year. Estimates of these four variables were available for a period of 20 years and a multiple regression analysis was done to determine the best fitting relationships for each age-group in the fishery. In this way, four equations were derived for predicting the catches of haddock at 2, 3, 4, and 5 or more years old respectively. This analysis was quite empirical and based on the assumption that catch and effort during the same year were linearly related, whereas it might have been more realistic to have assumed a proportional relationship and therefore to have done the regression analysis on the logarithms of the catches and amounts of fishing effort. Nevertheless the agreement between the theoretical and observed figures was statistically significant for each age-group except the 2-year-olds. Moreover, agreement between total catches and theoretical total (obtained by summing the predicted catches for each age-group) was statistically significant.

Having fitted a theoretical set of total catches to an observed series for the period 1932–1950 the authors showed that the method gave very good predictions for 1951 and 1952. In each case it was necessary to make an estimate of the amount of fishing during each of these years and to be on the safe side, several estimates were given for a range of probable fishing efforts.

In this work, estimates of the total amount of fishing each year were not obtained by summing the annual amounts of fishing by each vessel. Instead, the catches per day's fishing by a selected group of large otter-trawlers were determined each year to provide indices of the availability of haddock in standard units. The total catches each year were then divided by the respective indices of availability to give annual estimates of the amount of fishing in "standard trawler days." This method is of particular interest in that it is an attempt to eliminate the effect on the estimated fishing effort of changes in the composition of the fleet or the gear. On the other hand, alternative forms of bias could have occurred, if the distribution of the standard trawlers on the fishing grounds was not always representative of that of the rest of the fleet.

In short, this paper gives a useful account of a method of predicting catches one or two years ahead, and has shown that for two years at least, the predictions were extremely good.

R. Jones

U. Schmidt. "Beiträge zur Biologie des Köhlers (*Gadus virens* L.) in den isländischen Gewässern". Ber. Deutsch. Wiss. Komm. f. Meeresf., N.F., **14**, 1, S. 46–82, 10 Abb. Stuttgart, 1955.

While the various stocks of cod and haddock in northern European waters have been made the object of detailed investigations, the saithe seems to have been largely neglected by fishery biologists in the past. However, the recent increase in the importance of this species to the fishing industry has led at least two countries, viz., Germany and Norway, to include saithe investigations in their research programmes. This paper is an account of the first results of the German investigations on the Icelandic saithe stock.

The material comes from two sources — samples and observations collected on three voyages to Icelandic waters on board commercial trawlers in 1952, 1953, and 1954, and market sampling carried out each year since 1946.

In his review of the methods used, the author gives the interesting information that in older fish the scales fail to show all the zones, whereas the otoliths showed clear and well defined zones which could easily be interpreted, even at such great ages as 20 years.

It is noteworthy that the author uses 1. May as the change-over date from one year-class to the next, this being the *end* of the spawning season. This procedure is unconventional, and to the reviewer also seems inconvenient, since it leads to the confusing situation of having one year-class represented by two different age-groups in the same calendar year. In spring-spawning species it is usually advantageous to use 1. January as the change-over date.

Dr. SCHMIDT's investigations were concentrated on the spawning stock of saithe occurring in the spring on the banks to the south-west of Iceland. The age analysis showed that this population consisted of a large number of age-groups; in 1954 there were as many as twenty, ranging from 4- to 23-year-old fish. Usually one or more broods predominate in the catches, and great fluctuations take place in the abundance of the different broods. Good year-classes were those of 1935, 1937, 1939, and 1944.

The history of the 1945 brood is particularly interesting. According to both Icelandic and German investigations this year-class was very abundant up to the age of 6 years, after which it almost entirely disappeared. Several explanations are suggested, but the author seems most inclined to believe that an emigration to the North Sea or the Norwegian coast took place, which drew away the major part of this year-class permanently from Icelandic waters. In view of the fact that the saithe is a bentho-pelagic species, with great swimming power, a large-scale trans-oceanic migration of this type does not seem unlikely, even though it has never been observed in other gadoid species.

The age at first maturity, as determined from the spawning zones in the otoliths, was found to vary between 4 and 9 years, the bulk of the fish (ca. 70%) maturing at age 5 and 6.

The growth of the saithe, as shown by the mean lengths of the age-groups, is discussed in detail. When the growths of fish which have spawned several times, first-time spawners, and immature fish of the same age were compared, a gradation in the descending order mentioned above was found, which revealed the relationship between growth-rate and maturity usually found in fishes. Differences in growth are also shown to occur in Icelandic waters

according to geographical locality. It is suggested that these differences are related to temperature, as the growth of the fish from the south-east coast, where cold-water masses prevail, is less than that of the fish living in the warmer waters of the west coast.

In the last chapter, entitled "Depth Distribution of the Saithe Shoals and Diurnal Migrations", the author records some very interesting observations on fish behaviour. Records of catch per hour's fishing by day and by night showed a similar type of diurnal fluctuation in several different localities and at different seasons of the year. Catches are poorest in the first few hours after midnight. At dawn a rapid increase occurs, and the highest catch of the 24 hours is usually taken before noon. These regular variations in the size of the catch are ascribed to diurnal vertical migration. This theory is supported by some very convincing echo-traces showing saithe ascending from the bottom, in the pelagic phase, and descending to the bottom in the morning.

An analysis of the length composition of the catches at various hours revealed that relatively more small fish were caught by night and more large fish by day. This is interpreted as a result of a difference between the times of the vertical migrations of the two size categories, the smaller fish being predominantly demersal during the night and pelagic during the day, and the larger fish behaving in the opposite fashion. A critical reader may not be quite convinced that the author has succeeded in showing that the direction of the diurnal migration of the small fish is exactly opposite to that of the large fish. The tables and figures show percentages only, and it seems that a simpler and equally possible explanation of the size variation in the catches may be that the smaller fish in general have a greater tendency to remain near the bottom, while the larger ones undertake regular vertical migrations.

Dr. SCHMIDT's paper is a very welcome addition to the literature on the European stocks of gadoids. His study of diurnal migration is particularly valuable; this is a phenomenon of great practical significance in bentho-pelagic species.

G. Sætersdal

N. B. Marshall. "Alepisauroid Fishes." Discovery Rep., **27**, pp. 303–336, 9 figs., 1 plate. Cambridge, 1955.

The alepisauroid fishes are voracious bathypelagic forms, which together with the Myctophoidea constitute the order Iniomi. The material studied consists of a small number of specimens from the Discovery Collections. They represent three of the six families which form the suborder Alepisauroidea.

Two new species of scopelarchids, *Scopelarchus cavei* and *Neoscopelarchoides dubius*, are described, and *N. elongatus* (NORMAN) is redescribed. A description of a late larval stage of a *Neoscopelarchoides* species is also given, and it is shown that the curious large larval form *Benthalbella infans* ZUGMAYER belongs to this genus. The relationships and synonymics of the genera of Scopelarchidae are discussed, and it is concluded that the family can be divided in two genera only, *Scopelarchus* and *Neoscopelarchoides*.

A useful key to the known species of Scopelarchidae is given, but *Neoscopelarchoides* (*Benthalbella*) *infans* is missing from the list. Although the species may not be considered as a genotype, on account of ZUGMAYER's uncertainty as to its systematic position, the specific name must be retained.

In the next section of the systematic part of the paper a new paralepid, *Macroparalepis molestus*, is described. As the characters of this species are intermediate between those of the two genera *Macroparalepis* and *Stemonosudis*, into which HARRY has divided the genus *Macroparalepis* EGE 1933, MARSHALL proposes that this division should not be retained.

The family Anotopteridae was recently revised by HUBBS, MEAD, and WILIMOVSKY, who concluded that only one species, *pharao*, of the genus *Anotopterus* can be recognized. MARSHALL describes two new specimens of this rare fish and finds some indication that this species may be differentiated into northern and southern forms. More data are necessary to show whether the observed differences are significant, however. In his discussion on the distribution of this species, MARSHALL draws attention to the possibility considered by HUBBS *et al.* that *Anotopterus*, like certain ceratioid fishes, "occurs chiefly as young to small individuals in the warmer waters and as large adults only in colder waters towards the poles." To the reviewer it seems that this statement may be a misinterpretation of the fact that large adults of several bathypelagic fishes are hardly ever caught by research ships, partly, perhaps, because of their relative scarceness, and partly because they are able to avoid the small and slowly moving gear used. They are known mainly from occasional catches by the far more effective and intensive commercial fisheries and mostly from those colder areas where the temperature conditions do not keep them away from the relatively shallow depths in which commercial fishing is carried on.

In the second part of this paper the alepisauroids are compared with the myctophoids. Most interesting correlations are found between the development of the swim-bladder, the ossification of the skeleton, and the setting of the pectoral fins. The conclusion is reached that among the pelagic families of the Iniomi the alepisauroids have been adapted for dealing with large prey, since they have extraordinarily distensible stomachs and body walls and no or few scales, in contrast to the planktonic feeding Myctophidae. In these discussions of the functional morphology of the Iniomi MARSHALL puts forward many fascinating ideas about the various adaptations to deep-sea conditions.

In the concluding section MARSHALL remarks that his studies "have done little to dispose of the idea that the Iniomi may be no more than an assemblage of lineages, each having attained certain morphological features." Nevertheless he finds the order "a convenient gathering of those isospondyloid fishes with more specialized jaws."

Like his recent book, *Aspects of Deep Sea Biology*, this paper emphasizes the wide range of MARSHALL's knowledge of deep-sea fishes and the soundness of his views on the many difficult problems concerned with their biology and classification. Students of oceanic ichthyology look forward with the greatest pleasure to his further studies of these fascinating fishes.

E. Bertelsen

E. Fabricius. "Aquarium observations on the spawning behaviour of the char, *Salmo alpinus*." Rep. Inst. Freshw. Res., Drottningholm, 34, pp. 14–48, 10 figs. Lund, 1953.

E. Fabricius & K. J. Gustafson. "Further aquarium observations on the spawning behaviour of the char, *Salmo alpinus* L." Rep. Inst. Freshw. Res., Drottningholm, 35, pp. 58–104, 15 figs. Lund, 1954.

These two papers represent a substantial addition to the growing body of work on the spawning behaviour of salmonid fish and are perhaps particularly interesting in that they describe this behaviour in a salmonid which does not always spawn in running water and which may use spawning sites which differ markedly from those generally used by other members of the group.

The first paper gives an account of the observations made on a limited number of fish and this description is amplified by the account presented in the second paper.

When placed in a tank male char quickly established territories. If the tank was large enough each male could establish a territory of its own, but if a number of males were confined in a small tank one became dominant after a series of fights and then guarded the whole tank as his territory. Aggressive char attack moving objects of almost any size, shape, and colour, but red objects were attacked more frequently than any others. This suggests that the sight of the red colour in the spawning dress is one of the stimuli releasing aggressive behaviour.

Spawning took place during the day time in a range of light conditions varying from dim daylight to the bright illumination needed for photography. Temperature fluctuations over the range of 3·5° to 12·5°C. did not disturb spawning. Two types of nest-digging movements were observed in the females. In the first type, which occurred less frequently, the female remained in one place and, without turning on her side, performed very rapid and powerful swimming movements, which swept sand and other loose material away. The other type of movement, which was observed more often, was that commonly seen in other salmonids, in which the female turned on her side and performed a series of vigorous flapping movements with her tail. Experiments were carried out on the selection of nest sites by the female and the results showed that nests were most often excavated in coarse ("walnut-sized") gravel. Visual stimuli seem to govern the selection of a nest site and it was found that the female would carry out normal digging movements over coarse gravel which had been covered with a sheet of glass. In this respect the char would seem to differ from other salmonids, e. g., brown trout, in the case of which there is evidence that the existence of currents flowing down through the gravel is the factor governing the choice of nesting site.

Pair formation usually began when a female invaded the territory of a male. At first she was attacked but this aggressive behaviour of the male was soon replaced by courting, during which the male circled round the female continuously. When ready to spawn the female suddenly stops in the centre of the pit forming the nest, lowers her anal fin, bends her body backwards, trembles, and opens her mouth. The male responds by swimming up parallel with the female and both fish then swim side by side across the

pit, extruding their sexual products. After between one and five spawning acts the female performs snake-like undulating movements which sweep all the eggs down into crevices at the bottom of the pit. The female then begins digging again on the edge of the pit, an activity which both fills the old pit and makes a new one. Every female made several nests and usually performed more than one spawning act in each. The male usually remains with the female until she is spent and then abandons her for a new mate. One male could spawn with six females successively. The female remained at the nest site for some days after spawning and often defended the area as a territory.

The spawning behaviour is carefully analysed and its relationship with non-spawning behaviour is discussed. In particular, the authors compare their concept of the hierarchical organization underlying spawning behaviour in the char with that put forward by JONES and BALL for salmon and brown trout (British Journal of Animal Behaviour, **2**, 103–114, 1954), with which they do not wholly agree.

It is clear that more studies of this kind would do much to increase our knowledge of fish behaviour and it is also evident that unless papers on behaviour are to be merely descriptive, an attempt must be made to analyse and collate the information obtained. At the same time, this analysis has its dangers in that it can lead, as the authors of these papers are no doubt well aware, to the erection of categories which may be too rigid and which would produce a series of pigeon holes into which observations are forced rather than fitted.

K. A. P.

B. T. Hepper. "Environmental factors governing the infection of mussels, *Mytilus edulis*, by *Mytilicola intestinalis*". Min. Agric., Fish., & Food, Fish. Invest., Ser. 2, **20**, 3, pp. 1–21, 8 figs. London, 1955.

In the steady stream of papers dealing with the relation between *Mytilus* and *Mytilicola*, set going by the 1950 calamity in the commercially important Zealand mussel district, HEPPER's contribution is very welcome indeed. Mussel farmers in western Europe have to face the fact that sooner or later they may have to cope with this parasite. An understanding of the effect of ecological conditions on the rate of infection may help them to deal with the problem. In this it is helpful to realize, firstly, that both sexes of *Mytolicola* must meet in one and the same host before reproduction is possible; secondly, that the larvae produced will rarely if ever stay in the intestinal tract of the primary host, but are set free to start a planktonic life, be it of only short duration; and thirdly, that mussels of the genus *Mytilus* are the regular hosts. The level of infection in oysters, cockles, and other shellfish living in the same body of water is always so very much lower than in mussels that it seems at least doubtful whether a *Mytilicola* population could maintain its existence in the absence of mussels.

HEPPER realizes that any method of ridding the mussels of their parasites would be costly to operate, and that it would be necessary to repeat the treatment at intervals to prevent serious re-infection. HEPPER's efforts to develop such a method for experimental purposes did not give encouraging results (nor, incidentally, did the countless efforts made by the reviewer).

Ecological observations demonstrate, however, that mussels may live, grow, and fatten even in the presence of *Mytilicola*. Analysis of numerous samples of mussels collected in several British estuaries form the bulk of HEPPER's paper. His sketch maps are helpful, but foreign readers would certainly have welcomed a general small-scale map to enable them to locate the geographical position of the estuaries investigated. The conclusion that mussels raised from the bottom are less infected than those not so raised is of considerable practical importance, and tallies with observations made in other countries. The figures in the tables should, however, be read with care, because the dates of sampling are not indicated (the level of infection is often much higher at the end of the summer season than in late spring) and also because the mussels from higher levels are of a smaller size than those from deeper water. If the difference is great one must take into account the fact that the bigger the mussel the more water it filters, so that it has a greater chance of ingesting a *Mytilicola* copepodid along with its food. Indeed, the tendency of the copepodids to move downwards is probably the more important factor in bringing about the differences observed.

From the observation that the highest levels of infection are to be found in the central part of the Milford Haven estuary HEPPER concludes that *Mytilicola* is best suited by a fairly low salinity and does not thrive in fully marine conditions or in water of very low salinity. It should be borne in mind, however, that another important factor operating in an estuary is the number of copepodids per unit of water. Near the mouth of an estuary, when the tide is high, the mussels are bathed in fully marine water which is poor in *Mytilicola* larvae; in the upper part of the estuary, when the tide is low the mussels are in water of low salinity, containing few if any *Mytilicola* larvae. It is evident that the mussels living in the central section have a greater chance of becoming infected, if the distribution pattern of the copepodids is taken into consideration. Whether salinity *per se* plays any part in this is doubtful.

HEPPER is right in concluding that mussels living under otherwise optimal conditions can become of good quality even in the presence of fair numbers of *Mytilicola*, and that it is the mussels living under unfavourable conditions which suffer most from these parasites. It is, however, the reviewer's experience that even the finest feeding conditions cannot prevent a serious loss of condition whenever the level of infection becomes very high, i. e., over twice that indicated by HEPPER's figures, especially when swarms of young parasites make their appearance.

The application of the results of HEPPER's observations is that raft culture would be the best in a *Mytilicola*-ridden area. The costs of construction and maintaining rafts are prohibitive, however, unless the price paid for marketable mussels can be raised to the level prevailing along the Mediterranean coasts. HEPPER believes that a system of raised cultivation, like that in use in the Bay of Aiguillon (France), might suit British mussel farmers in areas where *Mytilicola* abounds. But it is open to doubt whether British mussel farmers would be satisfied with the rate of growth and fattening prevailing in the Bay of Aiguillon, even though it entails a lower level of *Mytilicola* infection.

P. Korringa

D. A. Hancock. "The feeding behaviour of starfish on Essex oyster beds". Journ. Mar. Biol. Assoc. U.K., **34**, 2, pp. 313–331, 3 figs., 1 pl. Cambridge, 1955.

In many oyster districts in the temperate zone the starfish is regarded as the worst enemy of oysters. Oystermen may go to considerable expense in their efforts to control this pest by either mechanical or chemical means. It is therefore only logical that the staff of the Fisheries Laboratory at Burnham-on-Crouch, searching for ways to rehabilitate the formerly flourishing oyster industry in Essex waters, should pay due attention to these voracious echinoderms. Field observations and laboratory experiments carried out by Mr. D. A. Hancock clearly demonstrate that the relation between starfish and oyster is not so simple that it can be depicted in black and white; in reality, all intermediate shades are required.

If the European starfish, *Asterias rubens*, is given a free choice, it will, when still young, feed almost exclusively on barnacles. The favourite food of the larger starfish is without any doubt the mussel, *Mytilus edulis*. As long as mussels are available, other shellfish in the immediate vicinity have little to fear. It is not yet clear whether it is the special flavour of the mussel or whether it is easier to open that is the main reason for the starfish's preference. Mussels do not occur in abundance in the Essex rivers, however. Among the shellfish species which do occur there in fairly large numbers, the larger starfish definitely prefer to feed on *Crepidula fornicata*, a serious competitor to the oyster. Both in the field and in the laboratory the number of oysters devoured by starfishes appeared to be hardly worth mentioning in comparison with the losses suffered by *Crepidula*. Only when *Crepidula* is relatively scarce and oysters occur in fair numbers will more oysters be killed. Under the present conditions in the Essex rivers *Asterias* is by no means the most important cause of mortality among oysters and oyster spat; it may even provide some measure of control over the pests such as *Crepidula*, *Balanus*, *Elminius*, and even of the fearsome drill *Uroslapinx*, and may therefore be regarded as beneficial to the oyster population. Another starfish of common occurrence in the Essex rivers, the sunstar *Solaster papposus*, appeared to be harmless, as it ate a young oyster only very occasionally. Its favourite food appeared to be the common starfish, *Asterias rubens*! If the latter is to be considered as beneficial to the oyster population then the former's influence on the oyster industry could very well be regarded as of a truly negative character! The same holds good for the stone crab, *Hyas araneus*, which appeared to prey on *Asterias rubens*.

All these interesting observations clearly demonstrate how complex Nature can be, and how careful one should be in assessing the factors which maintain a natural equilibrium. Nevertheless, oyster farmers should not conclude from this paper that the starfish must henceforth be considered their friend! Though it is true it destroys numerous *Crepidula*, it has so far never wiped out any of the dense *Crepidula* beds characteristic of the derelict oyster grounds in the Essex rivers. Evidently *Crepidula*'s rate of reproduction can keep pace with the losses. Further, if only 1 oyster is eaten — more or less accidentally — among 100 *Crepidula*, the life of that single oyster may very

well be more valuable to the oyster farmer than the death of the 100 *Crepidula*. Furthermore on semi-derelict grounds one aims, not at the natural equilibrium, but at the rehabilitation of the oyster area. This requires a considerable reduction of the *Crepidula* population and a corresponding increase in the number of oysters, both old and young. If this purpose can be attained by some means or other, starfish can no longer be regarded as harmless or even helpful creatures, and their control will become a necessity. Which method of control should then be chosen is not clear from HANCOCK's paper, for though he found that quicklime worked well under laboratory conditions, application in the field has not been a success so far in European waters.

The whole problem strikingly resembles that in fruit orchards. In semi-derelict orchards one finds a variety of pests together with their parasites and predators. A fairly stable equilibrium prevents really serious outbreaks of any one pest. The annual yield is limited and the quality of the fruit is at most moderate, never perfect. In a modern orchard, in which numerous measures of control are in operation, the annual yield is much higher, the quality of the fruit considerably better, often perfect, but the natural equilibrium is completely destroyed, and one must watch constantly for signs of serious outbreaks of pests and immediately take whatever action appears to be necessary. Intensive shellfish farming on a modern scale reveals very similar characteristics in comparison with the natural beds or derelict grounds.

P. Korringa

L. M. Dickie. "Fluctuations in abundance of the giant scallop, *Placopecten magellanicus* (GMELIN) in the Digby area of the Bay of Fundy." Journ. Fish. Res. Board Canada, **12**, 6, pp. 797–857, 16 figs. Ottawa, 1955.

There have been marked fluctuations in landings from the Digby scallop fishery since it was begun in 1920. Periods of bad weather and changing techniques might have affected the yield from the fishery but the author in a comprehensive and very detailed account has shown that these factors have little effect on the annual production. Changes in yield are due, mainly, to fluctuations in the population of market-sized, 6-year-old scallops.

The fishery is described and methods of assessing abundance are discussed in detail. Changes in population have been evaluated by analysing catch records of a proportion of the fleet and by special "census fishing" checked by marking experiments and submarine photography. Results obtained by each method show good agreement. In analysing catch records allowance was made for the number of days fished in each season, the efficiency or otherwise of a particular boat and crew, number and size of drags used, natural mortality, etc. An equation has been evolved to take these variables into account. Abundance was assessed by calculation from the catch records of the sample fleet alone and from the sample and whole fleet combined. The yield in pounds of scallop meat as calculated by both methods showed good agreement, though that based on results from the sample fleet alone would appear to be the more accurate.

Abundance calculated from census fishing conducted in 1950, '51, and '52 was checked against the abundance from landing statistics and a similar pattern was observed. The size of the scallop population was obtained by making standard hauls and calculating the density after allowing for the size of the drag and its efficiency and correcting for the area of the ground. Recovery of tagged scallops and submarine photography of the grounds provided alternative methods of estimating density and total population. As all landings are recorded in terms of weight of meat, it was necessary to convert the population, as calculated, into pounds of "meats" in order to obtain comparable figures. The author concludes that his estimates of the actual scallop population — some 1·7 million pounds in 1953 — is of the correct order of magnitude and that the methods of assay are sufficiently accurate to reflect actual changes in the population.

Reasons for the fluctuations in the population are considered. From the size distribution of the scallops it is apparent that good landings in any year are dependent on good recruitment, into the population, of earlier year-classes. Relative abundance and seasonal water temperatures for the period from 1930 to 1953 show a close relationship if the abundance is plotted against temperature 6 years' previously, i. e., at the time the scallops were recruited into the population. Apparently high average temperatures result in good settlement and six years later in a good yield of catchable scallops. The influence of temperature is apparently two-fold. 1) High temperatures result in rapid larval development and good survival, and 2) these conditions occur when there is little exchange of water between the Bay of Fundy and the sea outside, so that larval losses are correspondingly reduced.

In the course of calculating the population the author has made, in addition, useful and interesting observations on annual mortality (ca. 10%), on meat yield (meats from inshore scallops were heavier than those from deep water), on the catching efficiency of scallop drags (5% to 12% depending on type of ground), and on the localized setting of young scallops resulting in the so-called "shifting" of the grounds.

G. D. W.

K. Tiews. "Einfluss der Gezeiten und der Wassertemperatur auf die Garnelenfischerei". Ber. Deutsch. Wiss. Komm. f. Meeresf., N.F., **13**, 3, S. 270–282, 6 Abb. Stuttgart, 1954.

In this paper the effect is shown of the strength of the tidal currents and of the water temperature on the catches of shrimp (*Crangon vulgaris*) per unit effort on the Büsum (W. Germany) shrimp grounds.

The Büsum shrimp fishermen leave port in the morning and return in the afternoon; the time of absence depends on the tide. Therefore in order to get comparable figures the daily catches must be referred to a certain number of hours of absence. If these figures are correlated with the variations in the velocity of the tidal current occurring on that day it appears that there is a marked positive correlation. At spring tides the catches are larger than at neaps.

This phenomenon can be explained in two ways. One is that the population losses on the shrimp grounds caused by continuous fishing are replaced faster during spring tides, as a strong current favours the transport of shrimps to the fishing grounds from other unfished grounds. Another explanation is that the turbidity of the water is greater at springs than at neaps; from aquarium tests it is known that the shrimp buries itself in daylight and becomes active again in the dark. It is more likely to be caught in the active state than when it is buried in the sand. The greater turbidity of the water would stimulate the shrimp to greater activity, since it would diminish the light on the sea bottom.

The author has also investigated the relation between the size of the catches and the temperature. He found that the rise in temperature from the beginning of the season until August coincides with an increase in the catch per day's absence; the rise is more rapid at temperatures above 16° C. From July to September a change of 1° brings about a difference in the catch per day's absence of about 100 kg. With rising temperature at values above 16° the difference is greater than when the temperature begins to fall after the maximum is reached in August.

As the landings during the summer months make up the larger part of the total landings in the year, a high temperature in summer results in a rich average catch for the year. Conversely many bad shrimp years may be attributed to the low temperatures in that year, especially in summer.

The reason for the influence of the temperatures on the catches may be that growth is faster with high temperatures, and in addition migration will be stimulated by high temperature, so that the gaps in the population caused by fishing are filled more rapidly.

B. Havinga

Corrigendum

Vol. XXI, No. 3, 1956, p. 266. The second and third terms on the right-hand side of the equation at the foot of the page should read as follows: —

$$\ldots -0.3943T + 0.007714T^2 \ldots$$

Current Bibliography

Prepared by the Editor with the Assistance of Mr. A. R. MARGETTS

NOTE. The scope of the Bibliography is limited in the main to the area covered by the Council's activities, but there are included papers of general interest relating to other areas in North Temperate and Arctic regions and exceptionally elsewhere. Limnological references are not as a rule given, but papers relating to brackish waters and to salmon and freshwater fish studied by the Council are included.

Subscribers and those on the distribution list wil receive regularly upon application to the General Secretary copies of the Bibliography printed on one side of the page only, for use in making up card indices.

The Editor will be glad to be advised of emendations and additions to the Bibliography.

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